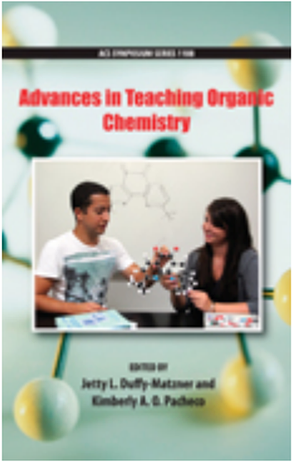


ACS SYMPOSIUM SERIES 1108

Advances in Teaching Organic Chemistry

EDITED BY

Jetty L. Duffy-Matzner and

Kimberly A. O. Pacheco

Downloaded by 89.163.34.136 on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.fw001

Advances in Teaching Organic Chemistry

Downloaded by 89.163.34.136 on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.fw001

ACS SYMPOSIUM SERIES **1108**

Advances in Teaching Organic Chemistry

Jetty L. Duffy-Matzner, Editor
Augustana College
Sioux Falls, SD

Kimberly A. O. Pacheco, Editor
University of Northern Colorado
Greeley, CO

Downloaded by 89.163.34.136 on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.fw001

Sponsored by the
ACS Division of Chemical Education

American Chemical Society, Washington, DC

Distributed in print by Oxford University Press, Inc.

Downloaded by 89.163.34.136 on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.fw001

Library of Congress Cataloging-in-Publication Data

CIP DATA

The paper used in this publication meets the minimum requirements of American National Standard for Information Sciences—Permanence of Paper for Printed Library Materials, ANSI Z39.48n1984.

Copyright © 2012 American Chemical Society

Distributed in print by Oxford University Press, Inc.

All Rights Reserved. Reprographic copying beyond that permitted by Sections 107 or 108 of the U.S. Copyright Act is allowed for internal use only, provided that a per-chapter fee of $40.25 plus $0.75 per page is paid to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, USA. Republication or reproduction for sale of pages in this book is permitted only under license from ACS. Direct these and other permission requests to ACS Copyright Office, Publications Division, 1155 16th Street, N.W., Washington, DC 20036.

The citation of trade names and/or names of manufacturers in this publication is not to be construed as an endorsement or as approval by ACS of the commercial products or services referenced herein; nor should the mere reference herein to any drawing, specification, chemical process, or other data be regarded as a license or as a conveyance of any right or permission to the holder, reader, or any other person or corporation, to manufacture, reproduce, use, or sell any patented invention or copyrighted work that may in any way be related thereto. Registered names, trademarks, etc., used in this publication, even without specific indication thereof, are not to be considered unprotected by law.

PRINTED IN THE UNITED STATES OF AMERICA

Downloaded by 89.163.34.136 on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.fw001

Foreword

The ACS Symposium Series was first published in 1974 to provide a mechanism for publishing symposia quickly in book form. The purpose of the series is to publish timely, comprehensive books developed from the ACS sponsored symposia based on current scientific research. Occasionally, books are developed from symposia sponsored by other organizations when the topic is of keen interest to the chemistry audience.

Before agreeing to publish a book, the proposed table of contents is reviewed for appropriate and comprehensive coverage and for interest to the audience. Some papers may be excluded to better focus the book; others may be added to provide comprehensiveness. When appropriate, overview or introductory chapters are added. Drafts of chapters are peer-reviewed prior to final acceptance or rejection, and manuscripts are prepared in camera-ready format.

As a rule, only original research papers and original review papers are included in the volumes. Verbatim reproductions of previous published papers are not accepted.

ACS Books Department

Downloaded by 89.163.34.136 on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.pr001

Preface

Unfortunately Organic Chemistry courses have often been seen as a gateway for weeding out students from various programs instead of a foundation course in constructing creative logic skills. Students approach these courses with a variety of attitudes that can affect their chances of learning. This text will incorporate studies on new teaching methods and their level of success as well what we know works to promote student learning and what does not. The text will also consider what variables control student achievement in an organic chemistry course and how well the concepts taught really correlate to the outside world. This symposium text will seek to illuminate the latest trends as well as some tried and true methods for teaching organic chemistry at both large and small institutions.

This book is based on a symposium held at the 242nd National American Chemical Society Meeting in Denver, Colorado on August 20, 2011. There were 16 oral presentations given and many lively discussions were held. The symposium was very well received and there was a strong interest in how different instructors approach teaching this topic and how things will evolve in the classroom as we move forward.

The text has several different themes. Organic chemistry wouldn't be organic chemistry without a very strong lab component. However getting students to engage in organic lab instead of just acting like cooks following a recipe can be challenging. The first part of the text has 4 chapters with ideas of how to revitalize the lab experience. Next we have a chapter from textbook author and master organic chemistry professor, Dr. Neil Schore, with words of advice of how he engages the masses in organic chemistry lecture. This is followed by four chapters with ideas of how to increase comprehension in lecture as well as predict student success rates. Next come two chapters that explore curriculum reform of the traditional organic chemistry classes to blends of freshman/organic and organic/biochemistry courses. Finally there are four chapters that examine the use of technology and how to teach students of the 21st century. Students don't read textbooks as they did in the past and the use of electronic material as instructional aides can be very important in reaching our students. These chapters provide insight into using podcasts, vodcasts, short online videos, online video tutorials, and chemistry applications for cellular phones to assist in teaching organic chemistry as well as to help students study and introduce topics outside of lecture time.

This book is targeted for all of us who struggle to make organic chemistry more comprehendible and at the same time instill our passion for the subject to our students. We hope it will be useful for those who are just embarking on this time consuming but rewarding journey as a chemical educator as well as for those of us who have been out in the field for awhile and are open to some new approaches.

We thank the authors for their timely contributions and their cooperation while the manuscripts were being reviewed and revised. Thanks are also due to the ACS Division of Chemical Education for sponsoring the 2011 symposium. We would also like to thank Dr. Mike McGinnis for his willingness to help with this project as well as co-moderate the symposium, the many reviewers for this text and the staff of the ACS Symposium Series.

Jetty L. Duffy-Matzner

Department of Chemistry
Augustana College
2001 S. Summit Avenue
Sioux Falls, SD 57197, U.S.A.
duffy@augie.edu (e-mail)

Kimberly A. O. Pacheco

Department of Chemistry and Biochemistry
University of Northern Colorado
501 20th Street
Greeley, CO 80639, U.S.A.
kimberly.pacheco@unco.edu (e-mail)

Downloaded by 89.163.34.136 on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.pr001

Editors' Biographies

Jetty L. Duffy-Matzner

J. L. Duffy-Matzner (Ph.D., UC, Davis) is an Associate Professor and Chair of the Chemistry Department, Augustana College (SD). She teaches general chemistry, organic, advanced organic and organic spectroscopy courses. Her research involves the synthesis of heterocyclic compounds with diverse applications such as fungicides, antibiotics, solar cells and chemosensors. She is a member of the ACS Organic and Chemical Education Divisions, Councilor for the Sioux Valley Local Section, Chair of the Awards Committee for the Midwest Regional Executive Board and serves on the Meetings and Exposition Committee. She was currently honored with the Vernon and Mildred Niebuhr Faculty Excellence Award.

Kimberly A. O. Pacheco

K. A. O. Pacheco (Ph.D., UNC-Chapel Hill) is an Associate Professor of Chemistry at the University of Northern Colorado. She teaches both organic courses for majors and nonmajors, Organic Synthesis and Stereochemistry, and Theory and Mechanisms in Organic Chemistry. Her research focuses on synthesis of photoactive compounds and formation of thin films for use in photovoltaic devices. She is a member of the ACS Chemical Education Division and has served on two ACS Organic Exam Committees. She also chaired the initial ACS First-Term Organic Exam Committee. She has been the advisor for the UNC ACS Student Affiliate Chapter since 2001.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ot001

Downloaded by CALIFORNIA STATE UNIV FRESNO on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch001

Chapter 1

Discovery-Based Labs for Organic Chemistry: Overview and Effectiveness

Norma Dunlap* **and Leah J. Martin**

Chemistry Department, Middle Tennessee State University,
Murfreesboro, TN 37132
***E-mail: ndunlap@mtsu.edu**

Although more common in general chemistry courses, a number of discovery-based or guided-inquiry laboratory experiments in organic chemistry have been reported over the past fifteen years. These are generally believed to be an improvement over traditional "cookbook" experiments, with increased student interest and engagement. A survey of the chemical education literature gives many examples, with most falling into one of just a few categories. Examples from each of these categories are summarized, as well as examples that focus on assessment of student learning and perceptions.

Introduction

Laboratories are a central component of the undergraduate organic chemistry curriculum, where students are taught techniques, research skills, and support for lecture material. For years educators have been looking at the effectiveness of science laboratories and the impact on student's learning, and there are many opinions on what constitutes an effective lab. Chemistry labs have been classified as expository, problem-based, inquiry or discovery (*1*). The types of lab share similarities but differ in respect to outcome, approach and

In Advances in Teaching Organic Chemistry; Duffy-Matzner, J., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2012.

Downloaded by CALIFORNIA STATE UNIV FRESNO on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch001

procedure, and there have been debates on which type of lab is most effective (*2–5*). *Expository*, also known as cookbook, verification, or traditional style, is the predominant laboratory style used in undergraduate organic chemistry laboratories. This type of lab has been defined as a deductive approach where students are given a problem and step-by-step instructions on how to reach a pre-determined outcome. The concepts covered in the laboratory will have been covered in lecture before the lab is performed. Although the majority of undergraduate labs use an expository approach, the method has been criticized by many educators and researchers. Advantages include ease of lab preparation and training of TAs, however expository labs involve little critical thinking (*6–8*). Increasingly, organic laboratories have incorporated some *discovery*, or *guided inquiry-based* labs. These are seen as more practicable labs than *open inquiry* and *problem-based* experiments, where students are expected to develop a procedure. In a typical discovery or guided-inquiry experiment, students follow a given procedure, collect their data, make observations and draw conclusions based on their results. The outcome varies from predetermined to undetermined. This is a more inductive approach than the expository labs, and develops critical thinking skills.

In discovery-based labs, the instructor does not give step-by-step instruction, but may give a general procedure. Students are playing the role as the discoverer in lab with less “guidance” from the instructor (*1*). Some evidence suggests that students learn more and are more engaged in a guided-inquiry lab or a discovery based lab than in the traditional, cookbook lab setting (*9*). For example, several General Chemistry labs were converted to guided-inquiry labs, and out of 300 students surveyed, 74% felt that their powers of observation were developed mor by the guided-inquiry labs than by verification labs. In the same survey, 68% felt that their understanding of concepts was enhanced more in the guided-inquiry labs. Discovery labs are inductive in nature, illustrate the scientific method, and connect theory with empirical data (*10*). Admittedly, students’ attitudes towards the labs vary; most would agree that their “problem solving skills” were used more, but they also found the laboratories more frustrating and difficult (*11*). Most of these studies have been conducted in general chemistry labs, but these open the idea that changing the traditional lab structure in organic chemistry may deepen students’ understanding of the subject.

As there are educators that are “pro-discovery”, there are criticisms of the style as well. It has been argued that if a student does not have basic knowledge of the material to be learned, they are unable to make the “correct” discovery, and it is unclear how a group of students can discover the same thing. Also, discovery labs are more time consuming and more challenging in regard to training of teaching assistants (*11*).

Although most of the research in the area of effectiveness of different lab types on student learning has been focused in the general chemistry laboratory courses, some studies have been published for the undergraduate organic chemistry laboratory. The goal of this chapter is to summarize representative examples of published discovery-based organic chemistry labs that can be implemented into the undergraduate curriculum, as well as the scant research that has been done on the *effectiveness* of discovery labs in the organic chemistry laboratory.

Summary of Discovery and Guided-Inquiry Labs

A survey of discovery and guided-inquiry labs specific for organic chemistry fall, for the most part, into a few different categories. These are: labs involving identification of unknowns, labs involving reaction analysis, and labs involving isolation and/or purification. Several published laboratory manuals have incorporated multi-step and guided-inquiry experiments, however the focus of this chapter is on experiments published in journals (*12*, *13*).

Downloaded by CALIFORNIA STATE UNIV FRESNO on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch001

Labs Involving Identification of Unknowns

Identification of unknowns lends itself well to discovery and guided-inquiry. The extent of critical thinking on the part of the student depends on how much is "unknown". For instance a common expository lab involves giving a table of compounds with ten different melting points and asking students to identify an unknown by a melting point. This would involve learning lab techniques, but little in the way of critical thinking. However, expanding the number of compounds in the table, as well as the extent of analysis, and including compounds with similarities leads to a more discovery-based approach. An example of this is the identification of a series of unknowns based on melting point analysis as well as IR and NMR spectroscopy (*14*). From a list of eighty-one compounds, students narrow down the possibilities based on melting point or boiling point. An IR is taken and analyzed in order to further narrow the possibilities by functional group. Final determination is based on NMR spectroscopy.

More advanced use of unknowns involves the reaction of an unknown, and then analysis of spectral data for identification of the product, and therefore of the starting material. A number of labs have been published using this approach, including functional group oxidation, aryl nitration, alcohol dehydration and nucleophilic addition to carbonyls. These are summarized in Figure 1.

In the first case, students are given an unknown that may be either an alkene, alcohol or ketone, with twelve possible structures (*15*). The first task is to identify the functional group by chemical tests and IR. The oxidation method proposed by the student is dependent on the functional group, and analysis of the carboxylic acid product is done by NMR. Although students are all carrying out the same reaction, they will obtain different products, and will need to analyze properties of the products and then work back to identify the starting material. The next two are variations of typical expository labs done in nearly every undergraduate organic chemistry lab. Nitration of methyl benzoate, as well as dehydration of cyclohexanol are standard labs. Modification of both of these to include four unknown starting materials, and analysis of the product by NMR adds the element of discovery (*16*, *17*). Students must analyze the spectroscopic data of the product in order to work back to the identification of the starting unknown. A final example is that of sodium borohydride and Grignard addition to unknown carbonyl compounds. The unknowns include an aldehyde, a ketone, an ester and an anhydride. Students carry out both reactions and analyze whether or not a reaction has occurred, as well as identity of a product in order to work back to identification of the unknown (*18*).

Downloaded by CALIFORNIA STATE UNIV FRESNO on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch001

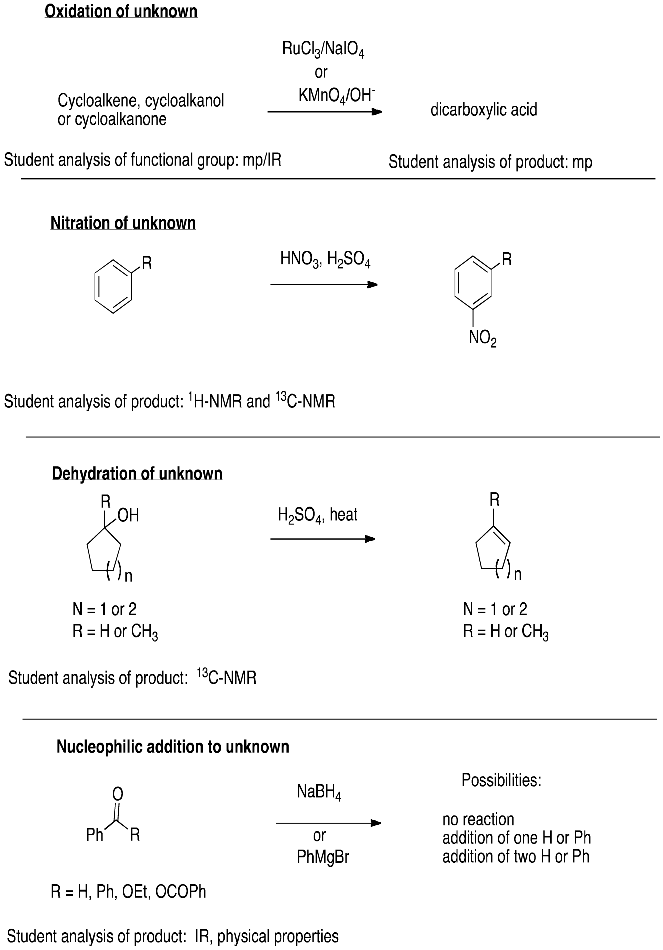

Oxidation of unknown
$RuCl_3/NaIO_4$
or
$KMnO_4/OH^-$
Cycloalkene, cycloalkanol or cycloalkanone
dicarboxylic acid
Student analysis of functional group: mp/IR
Student analysis of product: mp
Nitration of unknown
R
HNO_3, H_2SO_4
R
NO_2
Student analysis of product: ^1H-NMR and ^{13}C-NMR
Dehydration of unknown
R
OH
n
H_2SO_4, heat
R
n
N = 1 or 2
R = H or CH_3
N = 1 or 2
R = H or CH_3
Student analysis of product: ^{13}C-NMR
Nucleophilic addition to unknown
O
Ph
R
$NaBH_4$
or
PhMgBr
Possibilities:
no reaction
addition of one H or Ph
addition of two H or Ph
R = H, Ph, OEt, OCOPh
Student analysis of product: IR, physical properties

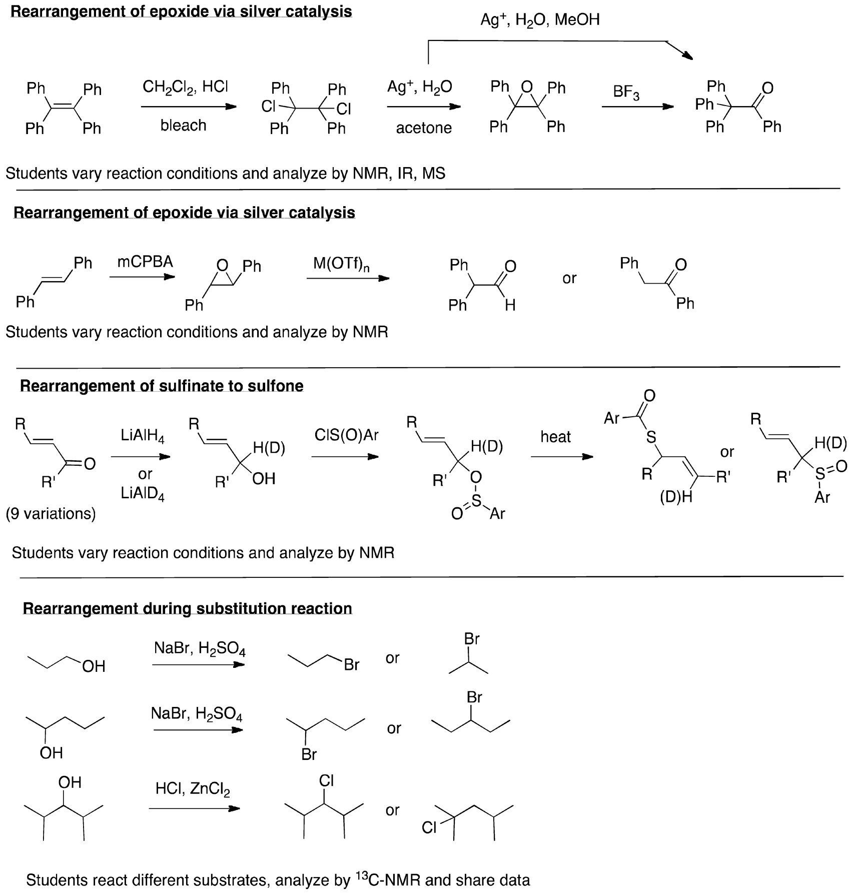
Figure 1. Examples of labs involving reaction and analysis of an unknown.

Labs Involving Reaction Analysis

Most of the published labs fall into this category and vary with the extent of discovery by the student. Several procedures result in various products based on mechanism, and the student's "discovery" involves both product analysis and proposal of mechanism. There are a few examples in which a rearranged product may be observed, either in an epoxide ring opening, or in an alkyl halide formation from an alcohol (*19–21*). Several more advanced labs have been reported, including a sulfinate to sulfone rearrangement, and a ring-closing metathesis (*22*, *23*). These are perhaps best suited for an upper level advanced synthesis lab, as they both deal with reactions not commonly covered in the typical two-semester organic sequence. Figure 2 gives examples of published labs that involve inquiry on the students' part on reaction mechanism, due to rearrangement that occurs during the reaction. For example, the epoxide rearrangement products (reaction

Downloaded by CALIFORNIA STATE UNIV FRESNO on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch001

2, Figure 2) arise from migration of either a phenyl or a hydride. Students need to think about migratory ability of the different groups, as well as the use of NMR to identify the aldehyde vs. the ketone product. In all cases, migration of the phenyl led to the aldehyde product. The discovery component in another example (reaction 4, Figure 2) involves understanding of possible carbocations rearrangements during substitution as well as ^{13}C-NMR interpretation. For example, reaction of 2-pentanol with HBr (NaBr, H_2SO4) may occur via to give 2-bromopentane (S_N2) or 3-bromopentane (S_N1 with hydride shift). In the first case, students will see five carbons signals, and in the second case, only three. In practice, students see a 3:2 ratio of 2-bromopentane to 3-bromopentane.


Rearrangement of epoxide via silver catalysis

Students vary reaction conditions and analyze by NMR, IR, MS

Rearrangement of epoxide via silver catalysis

Students vary reaction conditions and analyze by NMR

Rearrangement of sulfinate to sulfone

Students vary reaction conditions and analyze by NMR

Rearrangement during substitution reaction

Students react different substrates, analyze by ^{13}C-NMR and share data

Figure 2. Labs involving analysis of a rearranged product.

Several other labs involve the investigation of stereoselectivity , chemoselectivity and/or regioselectivity of a reaction, and are summarized in Figure 3.

Downloaded by CALIFORNIA STATE UNIV FRESNO on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch001

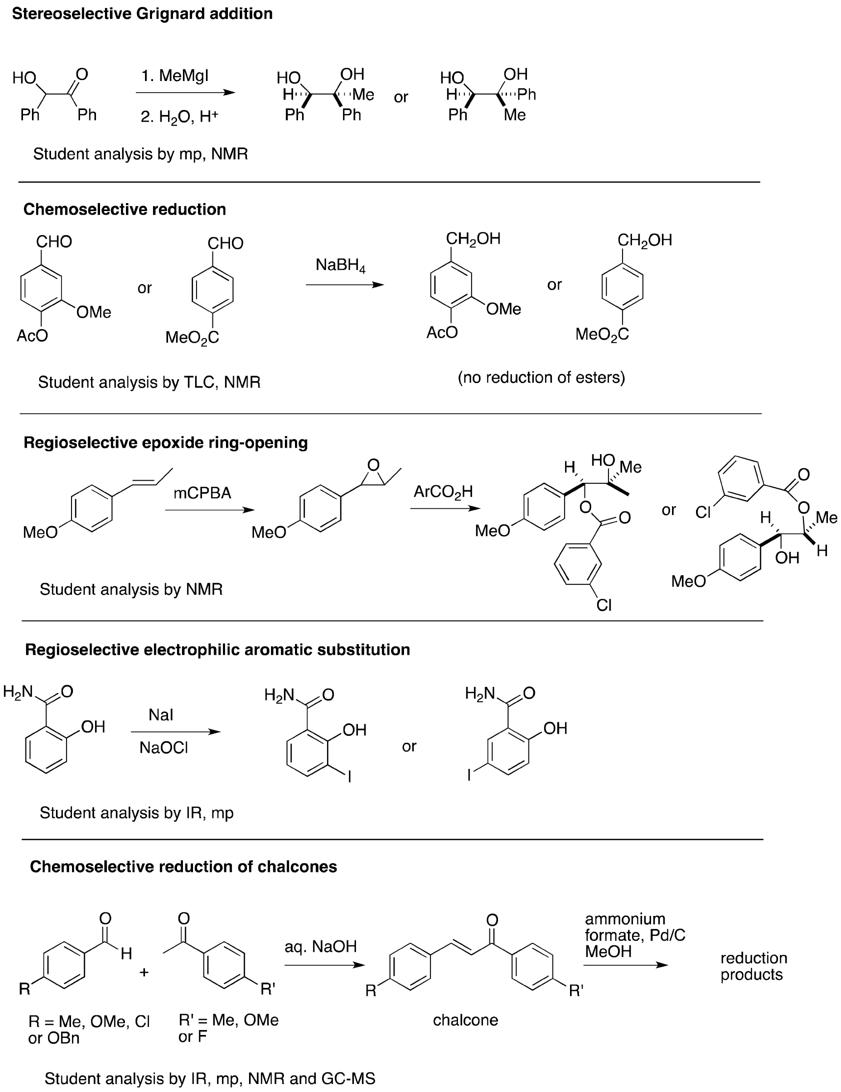

Stereoselective Grignard addition
1. MeMgI
2. H2O, H+
or
Student analysis by mp, NMR
Chemoselective reduction
NaBH4
or
Student analysis by TLC, NMR
(no reduction of esters)
Regioselective epoxide ring-opening
mCPBA
ArCO2H
or
Student analysis by NMR
Regioselective electrophilic aromatic substitution
NaI
NaOCl
or
Student analysis by IR, mp
Chemoselective reduction of chalcones
aq. NaOH
ammonium formate, Pd/C MeOH
reduction products
R = Me, OMe, Cl or OBn
R' = Me, OMe or F
chalcone
Student analysis by IR, mp, NMR and GC-MS

Figure 3. Labs involving analysis of stereoselective, chemoselective and regioselective reactions.

The discovery on the part of the student in these labs relies mainly on prediction of possible reaction products, and use of physical or spectroscopic techniques for verification. For example, in the addition of a Grignard reagent to racemic benzoin, all students carry out the same reaction, and determine the product based on melting point, with a discussion of diastereoselectivity (*24*). An example of a chemoselective reaction has students using one of two possible substrates, each with an aldehyde and an ester funtional group. Analysis of the product by NMR spectroscopy is used in order to identify which group(s) were

Downloaded by CALIFORNIA STATE UNIV FRESNO on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch001

reduced (*25*). Other examples of prediction and verification of regioselectivity in reactions include epoxide ring-opening and electrophilic aromatic substitution (*26*, *27*). Another example that falls into this category is the synthesis and chemoselective hydrogenation of a series of chalcones (*28*).

Labs Involving Purification

Several labs have been published that are an extension of the traditional purification labs involving distillation, recrystallization and chromatography. Varying techniques and/or samples lends the element of discovery to these labs. One example combines extraction, recrystallization and distillation into one experiment. Students perform the experiments with variable conditions for each technique, and share and discuss results (*29*). Another example involves the purification of "poisoned" Excedrin using extraction, chromatography and spectroscopy (*30*). Students' interest is heightened by the use of a familiar medicine. Another example is that of the isolation of components of plants by extraction, purification by chromatography and spectroscopic identification (*31*).

Discovery-Based or Research-Like Laboratory Courses

Most ambitious are the reports of entire courses developed on the basis of guided-inquiry labs. Of the published reports, a common feature is the development of technique using expository-type labs, followed by a multi-week combined experiment. By using the expository labs first, students gain confidence in their abilities before proposing and carrying out a multi-week discovery-based project. In one example, after gaining experience, students propose a multi-step synthesis, carry it out, and then write a formal report on their results (*32*). In another example, all students carry out a multi-week synthetic research project using a Wittig reaction, halogenation, elimination and then formation of metalloles (*33*). While perhaps the most interesting for students, these are challenging for the instructor.

Summary of Effectiveness of Discovery and Guided-Inquiry Labs

In many of the labs outlined in this chapter, informal observations were used to assess the effectiveness of the guided-inquiry labs and student learning. The instructors observed the questions that students asked during the lab, and concluded that the students in the guided-inquiry labs exhibited more independent thinking than in a traditional lab setting. It was also observed that students took more responsibility for what they were learning, felt the labs were more entertaining, and found the labs more rewarding than traditional labs (*15*, *29*, *33*).

Others, such as Stoub's purification lab, not only used informal observations, but also used student evaluations, end of year assessments, and reflections in a notebook to assess the effectiveness of the lab (*30*). Again, it was found that students asked deeper questions based on a deeper understanding of the laboratory, they took ownership of their work, and generally enjoyed the lab. There was no statistical analysis reported, but the laboratory handouts, student discussion questions, and instructor notes are provided in the supplemental material.

Miller and Leadbeater measured student learning versus students' perception of learning in their guided inquiry lab (*34*). A WebCT pre-laboratory test was given as a measure of prior knowledge of the material covered, which was broken down into three components: microwave energy, biodiesel, and esterification. The same test was given as a post-laboratory test to see if knowledge was gained. There was a statistical difference in scores on the pre-test vs. post-test, suggesting that the laboratory had a positive impact on students' understanding of the content. Along with the pre and post-test, a five point Likert-scale survey was administered which linked the test results to students' perception of their content comprehension. This survey was administered *via* WebCT before and after the laboratory as well. Their confidence from participating in this lab gave mixed results. In comparing the pre- and post-test, a statistical significance was observed for: comprehension of action of microwave energy in heating a reaction, knowledge of differences in microwave equipment, the concept of biodiesel, the actual synthesis and reaction conditions, and the students' abilities to interpret ^{1}H NMR. However, there was no statistical significance shown for: properties of biodiesel, mechanism of esterification, and trans-esterification.

Another very thorough assessment was carried out in Mohrig's three-week inquiry-based project for the synthesis and hydrogenation of disubstituted chalcones (*28*). Students synthesized and purified a disubstituted chalcone the first week. The second week was based on the regioselective hydrogenation of the chalcones, including analysis by TLC, IR, NMR, and GC-MS. For the final week students presented their data to their peers. The instructor acted as a research facilitator, and asked probing questions to assess understanding. Other students in the section typically added to the discussion for possible interpretations and general laboratory procedures. After input from others in the class on the presentations, the students wrote a formal lab report. Upon completion of the unit, students took an anonymous online survey to reflect their perception of the effectiveness of the laboratory. From the 547 students that participated in the free response survey, only 10% didn't like the experiment, while the aspects that students like the most were: use of spectroscopy (29%), diversity of lab skills (14%), approach allowing time for repetition (10%). The study also addressed issues involved in TA training. Although there was a weekly meeting and most TA's had taught guided-inquiry labs prior to this lab unit, the enthusiasm and amount of preparation influenced the results of this study. Results of questioning the participating students about the TA's showed that 32% of TA's made the student reason through problems on their own, 62% asked questions and "guided" the student in the proper direction, 3% answered all questions and corrected all problems, and 3% of the TAs did not know how to answer the questions.

Although there are many informal observations about the effectiveness of inquiry-based labs summarized in this chapter, there are few examples with formal assessment of the effectiveness. There is clearly a need for further research on the effect on student learning and attitudes toward organic chemistry, as well as a need to investigate TA training and their perceptions, as well as faculty. More research

Downloaded by CALIFORNIA STATE UNIV FRESNO on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch001

documenting and statistically analyzing aspects of the published guided-inquiry organic chemistry labs would also be helpful.

References

1. Domin, D. S. A review of laboratory instruction styles. *J. Chem. Educ.* **1999**, *76*, 543–547.
2. Ault, A. What's wrong with cookbooks? *J. Chem. Educ.* **2002**, *79*, 1177.
3. Mohrig, J. R. The problem with organic chemistry labs. *J. Chem. Educ.* **2004**, *81*, 1083–1085.
4. Monteyne, M.; Cracolice, M. S. What's wrong with cookbooks? A reply to Ault. *J. Chem. Educ.* **2004**, *81*, 1559–1560.
5. Hart, C.; Mulhall, P.; Berry, A.; Loughran, J.; Gunstone, R. What is the purpose of this experiment? Or can students learn something from doing experiments? *J. Res. Sci. Teach.* **2000**, *37*, 655–675.
6. Gallet, C. Problem-solving teaching in the chemistry laboratory: leaving the cooks. *J. Chem. Educ.* **1998**, *75*, 72–76.
7. Pavelich, M. J.; Abraham, M. R. An inquiry format laboratory program for general chemistry. *J. Chem. Educ.* **1979**, *56*, 100–103.
8. Hofstein, A.; Lunetta, V. N. The role of the laboratory in science teaching: neglected aspects of research. *Rev. Ed. Res.* **1982**, *52*, 201–217.
9. Allen, J. B. Guided inquiry laboratory. *J. Chem. Educ.* **1986**, *6*, 533–534.
10. Ricci, R. W.; Ditzler, M. A. Discovery Chemistry a laboratory-centered approach to teaching general chemistry. *J. Chem. Educ.* **1991**, *3*, 228–231.
11. Peters, R. S. *The concept of education*; London, Routledge & K. Paul: New York, 1967.
12. Mohrig, J. R.; Hammond, C. N.; Schatz, P. F.; Morrill, T. C. *Modern projects and experiments in organic chemistry: Miniscale and Williamson microscale*, 2nd ed; W. H. Freeman: New York, 2003.
13. Lehman, J. W. *Microscale operational organic chemistry*; Pearson Education, Inc.: Upper Saddle River, NJ, 2004.
14. Glagovich, N. M.; Shine, T. D. Organic spectroscopy laboratory: utilizing IR and NMR in the identification of an unknown substance. *J. Chem. Educ.* **2005**, *82*, 1382–1384.
15. Nielsen, J. T.; Duarte, R.; Dragojlovic, V. Oxidation of an unknown cycloalkene, cycloalkanol, or cycloalkanone to a dicarboxylic acid: a discovery oriented experiment for organic chemistry students. *Chem. Educ.* **2003**, *8*, 241–243.
16. McElveen, S. R.; Gavardinas, K.; Stamberger, J. A.; Mohan, R. S. The discovery-oriented approach to organic chemistry. 1. Nitration of unknown organic compounds. *J. Chem. Educ.* **1999**, *76*, 535–536.
17. Dunlap, N. K.; Mergo, W.; Jones, J. M.; Martin, L. Use of 13C-NMR in a dehydration experiment for organic chemistry. *Chem. Educ.* **2006**, *11*, 378–379.

Downloaded by CALIFORNIA STATE UNIV FRESNO on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch001

18. Rosenberg, R. E. A guided-inquiry approach to the sodium borohydride reduction and Grignard reaction of carbonyl compounds. *J. Chem. Educ.* **2007**, *84*, 1474–1476.
19. Christensen, J. E.; Huddle, M. G.; Rogers, J. L.; Yung, H.; Mohan, R. S. The discovery-oriented approach to organic chemistry. 7. Rearrangement of *trans*-stilbene oxide with bismuth trifluoromethanesulfonate and other metal triflates. *J. Chem. Educ.* **2008**, *85*, 1274–1275.
20. Moroz, J. S.; Pellino, J. L.; Field, K. W. A series of small-scale, discovery-based organic laboratory experiments illustrating the comcepts of addition, substitution, and rearrangement. *J. Chem. Educ.* **2003**, *80*, 1319–1321.
21. Kjonaas, R. A.; Tucker, R. J. F. A discovery-based experiment involving rearrangement in the conversion of alcohols to alkyl halides. *J. Chem. Educ.* **2008**, *85*, 100–101.
22. Ball, D. B.; Mollard, P.; Voigtritter, K. R.; Ball, J. L. Rearrangements of allylic sulfinates to sulfones: a mechanistic study. *J. Chem. Educ.* **2010**, *87*, 717–720.
23. Schepmann, H. G.; Mynderse, M. Ring-closing metathesis: and advanced guided-inquiry experiment for the organic laboratory. *J. Chem. Educ.* **2010**, *87*, 721–723.
24. Ciaccio, J. A.; Bravo, R. P.; Drahus, A. L.; Biggins, J. B.; Concepcion, R. V.; Cabrera, D. Diastereoselective synthesis of (+/-)-1,2-diphenyl-1,2-propanediol. *J. Chem. Educ.* **2001**, *78*, 531–533.
25. Baru, A. R.; Mohan, R. S. The discovery-oriented approach to organic chemistry. 6. Selective reduction in organic chemistry: reduction of aldehydes in the presence of esters using sodium borohydride. *J. Chem. Educ.* **2005**, *82*, 1674–1675.
26. Centko, R. S.; Mohan, R. S. The discovery-oriented approach to organic chemistry. 4. Epoxidation of p-methoxy-*trans*-β-methylstyrene. *J. Chem. Educ.* **2001**, *78*, 77–79.
27. Eby, E.; Deal, S. T. A green, guided-inquiry based electrophilic aromatic substitution for the organic chemistry laboratory. *J. Chem. Educ.* **2008**, *85*, 1426–1428.
28. Mohrig, J. R.; Hammond, C. N.; Schatz, P. F.; Davidson, T. A. Synthesis and hydrogenation of disubstituted chalcones. *J. Chem. Educ.* **2009**, *86*, 234–239.
29. Horowitz, G. A discovery approach to three organic laboratory techniques: extraction, recrystallization, and distillation. *J. Chem. Educ.* **2003**, *80*, 1039–1041.
30. Stoub, D. G. Discovery-based purification of Excedrin. *Chem. Educ.* **2004**, *9*, 281–284.
31. Whaley, W. L.; Rummel, J. D.; Zemenu, E.; Li, W.; Yang, P.; Rodgers, B. C.; Bailey, J.; Moody, C. L.; Huhman, D. V.; Maier, C. G.-A.; Sumner, L. W.; Starnes, S. D. Isolation and characterization of osajin and pomiferin: discovery laboratory exercises for organic chemistry. *Chem. Educ.* **2007**, *12*, 179–184.
32. Davis, D. S.; Hargrove, R. J.; Hugdahl, J. D. A research-based sophomore organic chemistry laboratory. *J. Chem. Educ.* **1999**, *76*, 1127–1130.

Downloaded by CALIFORNIA STATE UNIV FRESNO on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch001

33. Newton, T. A.; Tracy, H. J.; Prudente, C. A research-based laboratory course in organic chemistry. *J. Chem. Educ.* **2006**, *83*, 1844–1849.
34. Miller, T. A.; Leadbeater, N. E. Microwave assisted synthesis of biodiesel in an undergraduate organic chemistry course. *Chem. Educ.* **2009**, *14*, 98–104.

Downloaded by CALIFORNIA STATE UNIV FRESNO on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch001

Chapter 2

A Decade of Undergraduate Research-Inspired Organic Laboratory Renewal

Andrew P. Dicks*

**Department of Chemistry, University of Toronto, 80 St. George Street,
Toronto, Ontario, Canada M5S 3H6
*adicks@chem.utoronto.ca**

This chapter describes research opportunities available to chemistry undergraduates at the University of Toronto, and reviews how participating students have contributed to the development of new organic curricular materials during the last ten years. It is written from the perspective of a teaching faculty member whose primary area of research interest is the design of novel pedagogical laboratory experiments. The work discussed falls into one or more of the following five areas: (i) preparation and characterization of "real-world relevant" substances; (ii) greener and more sustainable reactivity; (iii) student-driven synthesis design and execution; (iv) plugging "pedagogical gaps"; and (v) collaborative and cooperative learning. Benefits of this approach to all parties involved (students, faculty and department) are particularly highlighted.

Introduction

Research Opportunities for Chemistry Undergraduates at the University of Toronto

At the University of Toronto St. George campus there are multiple opportunities to participate in research as an undergraduate student (*1*). As part of the Faculty of Arts and Science (FAS), the Chemistry Department participates in a centralized second-year Research Opportunity Program (ROP 299Y). This is a defined research course that lasts for 24 weeks (throughout the fall and spring semesters of the academic year). Eligible undergraduates must formally apply and need to have completed four full course credits for admission (but they may not

In Advances in Teaching Organic Chemistry; Duffy-Matzner, J., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2012.

have completed more than 8.5 credits - this identifies them as being in their second year of study). They are required to work in the laboratory of a faculty member for 8-10 hours per week for the duration of the project. It is additionally possible to participate in the Research Opportunity Program for twelve weeks during May-August, where the expectation becomes 16-20 hours of work per week. As stated on the ROP 299Y web site: "the program is completely voluntary and serves to enhance the fundamental connection between teaching and research in a research intensive university" (*2*). Each faculty member receives a small stipend for supervising a student (there is no upper limit on the number of undergraduates permitted to work on a single project). Around 15-20 chemistry faculty supervise a total of approximately 40 undergraduates in a ROP 299Y course every year.

The Department additionally offers summer scholarships for roughly 25 students that are enrolled in a chemistry program and have completed two or three years of undergraduate study. The majority of these are available via National Sciences and Engineering Research Council of Canada (NSERC) funding (NSERC Undergraduate Student Research Awards) and are tied to research faculty who hold NSERC grants. Additional money is available from industrial sources (currently DuPont Canada Inc., Xerox Research Centre of Canada) and local benefactors (Richard Ivey Foundation, graduate student ChemClub (*3*)). Awardees are required to work full-time for 16 weeks throughout the summer months. Thirdly, faculty members are able to supervise undergraduates in a two-semester fourth-year research course (CHM 499Y (*4*)). This is an essential component of several programs of study (e.g. Materials Chemistry, Synthetic and Catalytic Chemistry) but not all (*5*). Students must complete approximately 240 hours of work within the course and participate in a department-wide poster session where their work is formally assessed. They also routinely make oral presentations at local and national conferences. Typical enrollments range from 15-30 students each year.

The Teaching-Stream Faculty Model

The University of Toronto is a research-intensive institution with a total population of approximately 56,000 full-time undergraduates, 23,000 of which are part of the FAS at the downtown location. First-year undergraduate science classes are usually large (e.g. almost 2000 students annually take introductory organic chemistry at the St. George campus) where 35 chemical research faculty are located. In addition, eight instructors hold continuing appointments as part of a *faculty teaching-stream* which was instituted over a decade ago (*6*). These faculty members are formally trained in one or more of the following sub-disciplines: organic, inorganic, physical, analytical and environmental. They are typically required to undertake the following teaching tasks during the academic year: (i) coordination of a "team-taught" life science class (> 200 students); (ii) lecture instruction within the same course; (iii) operation of a multi-section laboratory with associated teaching assistant support; and (iv) delivery of an upper-level undergraduate "special topics" course. Not all teaching faculty will necessarily take on all such roles in one year. These responsibilities equate to an annual teaching commitment that is significantly greater than that assigned to a research faculty member, in accordance with the terms of the position (*6*).

As teaching faculty members are not appointed to the university School of Graduate Studies, they are unable to supervise graduate students who are pursuing a post-secondary qualification. However, it is strongly encouraged that they act as supervisors to undergraduate students, although this is not required on an annual basis. Supervision is easily facilitated through the described ROP 299Y and CHM 499Y project mechanisms, and also via the summer scholarship program. Teaching laboratory space is available during the academic year and summer months for wet chemistry to be undertaken. It is important to note that of the eight teaching stream faculty employed at the St. George campus, several engage in applied research whereas others focus on pedagogical and curricular development with students. Undergraduate supervision counts towards the "scholarly activities" component of a teaching faculty job. The department also sponsors an annual Chemistry Teaching Fellowship Program for graduate students who are specifically interested in pedagogical activities. After an application and project proposal process, four or five graduates receive a monetary award and individually collaborate with a faculty member regarding curriculum renewal. Several teaching faculty regularly take advantage of this scheme to develop (for example) a new suite of lectures, a set of classroom demonstrations or a novel laboratory experiment.

Organic Laboratory Curriculum Renewal

On being hired as a teaching faculty member in July 2001, this author planned to renew the undergraduate organic laboratory curriculum, primarily at the second-year and third-year levels. The department mounts a second-year organic course for life science students (annual enrollment ~1000), and an alternative course designed for chemistry program students (annual enrollment ~70). Either offering is considered a suitable pre-requisite for both a third-year organic synthesis course (described in the "Focus on Green Chemistry and Sustainability" section) and a third-year reaction mechanisms course (discussed in the "Discovery-Based and Collaborative/Cooperative Work" section). A number of "tried-and-tested" experiments were in place ten years ago which worked well, but did not necessarily reflect current research trends and had little element of student input (either in their design or operation). In addition, the physical laboratory space was renovated between 2003 and 2007, which provided further impetus for a new practical curriculum. An overarching goal was to develop enough new experiments that a degree of rotation could take place from year to year, in order to maintain a fresh atmosphere. Rather than simply implement existing experiments from commercial laboratory textbooks or the primary pedagogical literature, it seemed more appropriate to design novel modules that, where possible, reflected cutting-edge departmental research. There was also a specific intent to incorporate ideas surrounding green chemistry.

A decade ago there was no significant history of departmental undergraduates being involved in shaping curricula. However, it appeared possible within the context of ROP 299Y and CHM 499Y research projects, along with the efforts of interested summer volunteers. *Indeed, it quickly became apparent that students were the best people to become involved in this kind of initiative*. On interviewing several potential CHM 499Y students during the summer of 2001, there was a definite interest and enthusiasm shown by all of them. They were very committed and invested in improving the laboratory experience for future students. Some of the faculty concerns about the existing laboratory curricula were echoed by the undergraduates. Having taken a number of upper-level laboratory courses in different chemical sub-disciplines, they had interesting and insightful proposals about what new experiments they might work on.

In terms of curriculum renewal, the framework of a research course is beneficial in the context of project success. Both ROP 299Y and CHM 499Y courses require regular student-faculty contact, along with written progress reports, a poster presentation and an extensive thesis. A necessary aspect of every student thesis is the inclusion of materials to be directly incorporated into a future laboratory manual. Opportunities have arisen for students to give oral presentations at local, provincial and national conferences (these are described in more detail within the chapter conclusions). Much of the research is undertaken in undergraduate laboratory space, which affords the advantage of readily available glassware, apparatus and instrumentation. Several research faculty members have also kindly donated bench space for collaborative initiatives. As well as the faculty stipend mentioned previously for ROP 299Y student supervision, money provided through a Professional Expenses Reimbursement Allowance (PERA, \$1500 per year) has been used towards project costs. For example, these have included NMR training expenses, chemical costs, and money used for student registration at conferences.

Themes for New Organic Experiments

The organic experiments that have been designed by undergraduate researchers fall within one or more of five fundamental areas, which overlap in some cases. They are:

(i) preparation of substances having pertinence to “real life”
(ii) procedures highlighting green and sustainable principles
(iii) facilitation of student input and design
(iv) plugging “pedagogical gaps” in the chemical education literature
(v) discovery-driven laboratories with an emphasis on collaboration

Synthesis of “Real-World Relevant” Compounds

Of the several interdisciplinary undergraduate chemistry programs offered at the University of Toronto, the most popular one is the Biological Chemistry specialist (*7*). Students enrolled in this program generally have a keen interest in the *in vivo* mode of action of pharmaceuticals and related compounds. Preparation of the cough expectorant guaifenesin (**1**, Figure 1) and flutamide, a non-steroidal antiandrogen used to treat prostate cancer **2** facilitates an important connection between structure and biological activity (*8*, *9*). Each of these drugs is generated by a straightforward process (a Williamson ether synthesis and aromatic amine acylation, respectively) within a 3.5 hr. laboratory period. Guaifenesin can additionally be extracted from commercially available cough tablets, and its purity compared with that of the synthesized product. These two experiments are appropriate in a second-year introductory organic laboratory.

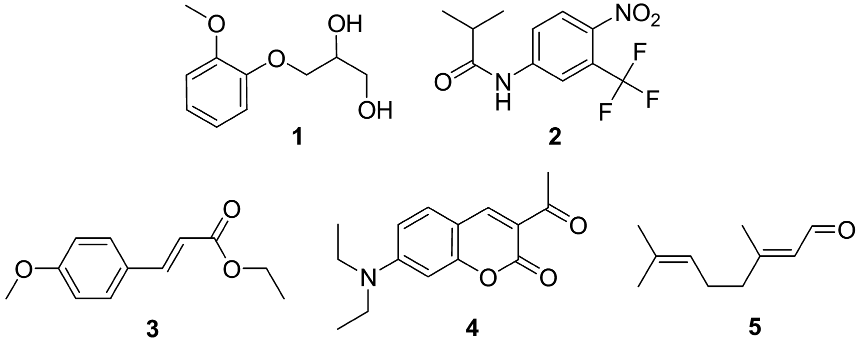


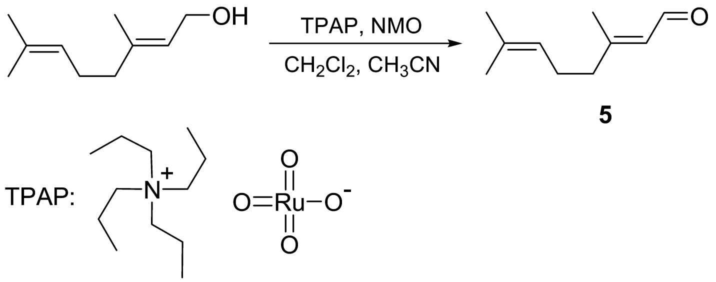
Figure 1. Structures of five "real-world relevant" synthetic targets

The conjugated cinnamate ester **3** is a sunscreen analog and readily synthesized in two steps starting from 4-methoxybenzaldehyde, by employing a Verley-Doebner reaction followed by an esterification (*10*). Its ability to absorb ultra-violet radiation is simply demonstrated by acquiring a UV-Visible spectrum and calculating the molar extinction coefficient at λ_{max} = 309 nm. Students learn that a common compound present in commercial sunscreens is actually the 2-ethylhexyl ester derivative of **3**, and propose reasons why this is the case in terms of hydrophobicity principles. In comparison, the bright yellow coumarin **4** exhibits beautiful blue fluorescence and is structurally related to several laser dyes (*11*). Facile preparation of this substance within one hour from readily available starting materials affords both measurement and discussion of its optical properties.

As well as synthesizing compounds that are visually appealing, it is instructive to stimulate the sense of smell in the organic laboratory. This is effectively achieved by the chemoselective oxidation of geraniol, a fragrant component of rose petals, to geranial **5** which displays a characteristic lemon odour (*12*). Even a small amount of product is immediately identifiable by smell and pleasing for students. Aspects of this upper-year experiment are used in the teaching of green principles and are discussed in the following section.

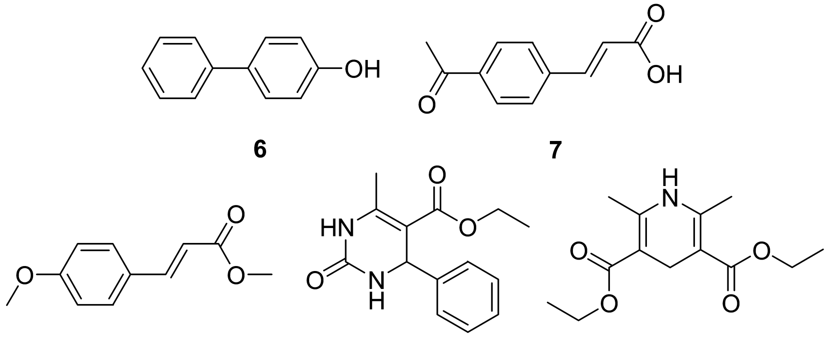
Focus on Green Chemistry and Sustainability

Several undergraduate research projects have contributed towards development of a new third-year course ("Organic Synthesis Techniques") which has a thread of green chemistry running through it (*13*). In this single-semester offering, an emphasis is placed on catalytic reactivity from both lecture and laboratory perspectives. As an initial example, preparation of 4-methoxybenzaldehyde used in the synthesis of sunscreen analog **3** (Figure 1) involves organocatalysis with β-alanine, an amino acid (*10*). Students are further exposed to transition metal catalysis via several reactions that are rotated from year to year. Ru(VII)-catalyzed oxidation of geraniol to geranial (Scheme 1) is a useful teaching tool for discussion of the "pros and cons" of many modern organic syntheses from a sustainability angle (*12*). The oxidant tetra-*n*-propylammonium perruthenate (TPAP) is readily synthesized by the laboratory instructor and used in catalytic quantities (12 mol% loading). The reaction is complete within 30 minutes under mild conditions at room temperature. Unfortunately, dichloromethane and acetonitrile are reaction co-solvents and a stoichiometric co-oxidant (*N*-methylmorpholine *N*-oxide, NMO) is necessary. These factors and others (such as a lack of catalyst recycling) detract from the environmental friendliness of the reaction. This becomes a "teachable moment" as students survey the recent literature and find alternative approaches to TPAP oxidations utilizing greener co-oxidants and an ionic liquid as solvent (*14–17*).



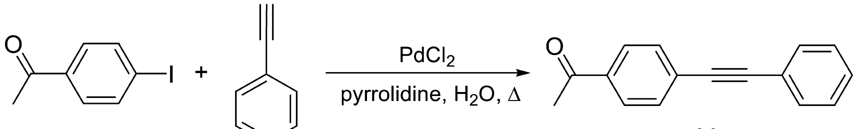
Scheme 1. TPAP-catalyzed oxidation of geraniol to geranial

Much attention has recently been directed towards palladium-catalyzed cross-coupling reactions, with the 2010 Chemistry Nobel Prize being awarded in the field (*18*). It is important that students be exposed to recent attempts to improve the sustainability profile of these transformations. Design and implementation of an aqueous Suzuki preparation of 4-phenylphenol (**6**, Figure 2) utilizing catalytic palladium on carbon (3 mg per student) has proved extremely successful (*19*). The reaction is performed in pure water as solvent and the product recrystallized from aqueous methanol in overall yields of 55-80%. This experiment has been adopted at the annual American Chemical Society Summer School on Green Chemistry and Sustainable Energy, which is attended by graduate students and postdoctoral research fellows. In a similar vein, an aqueous Heck reaction between acrylic acid and 4-iodoacetophenone furnishes 4-acetyl *trans*-cinnamic acid **7** under conditions of $PdCl_2$ catalysis (*20*). More recently, a Sonogashira reaction has been modified from the research literature and incorporated into Organic Synthesis Techniques featuring preparation of the alkyne 1-(4-(2-phenylethynyl)phenyl)ethanone **11** (Scheme 2, (*21*)). This approach employs catalytic $PdCl_2$ in a pyrrolidine:water solvent mixture. A review of aqueous reactions for the undergraduate teaching laboratory has recently been compiled (*22*).



6 **7** **8** **9** **10**

Figure 2. Compounds synthesized by "greener" routes



11

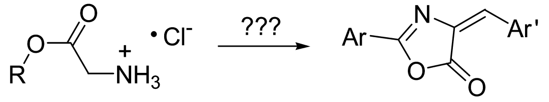
Scheme 2. Aqueous Sonogashira synthesis of 1-(4-(2-phenylethynyl)phenyl)ethanone

Several other procedures have been composed to showcase greener chemistry. A rapid and high-yielding Horner-Wadsworth-Emmons synthesis of methyl cinnamate ester **8** (Figure 2) is achieved under aqueous conditions, which greatly facilitates product work-up (*23*). Multi-component reactions are gaining attention from the green chemical community due to their relatively high atom enonomies (*24*). The well-established Biginelli and Hantzsch reactions (which are both over 100 years old) are run under solventless or low-solvent conditions to form a dihydropyrimidone **9** (*25*) or dihydropyridine **10** (*26*). These types of compounds are important from a pharmaceutical perspective as they exhibit vasodilatory properties, with some marketed as anti-anginal medications. Eliminating waste is one of the important Twelve Principles of Green Chemistry (*27*) and removing a reaction solvent is a significant step forward in this regard (*28*). The Biginelli reaction also exemplifies a green metric comparison between different catalytic approaches (Brønsted acid (HCl) versus Lewis acid ($ZnCl_2$)) (*25*).

Organic Synthesis Techniques is the capstone course in a novel interdisciplinary program (Synthetic and Catalytic Chemistry) that has been in place for the last three years in our department (*29*). The program blends necessary analytical, biological, synthetic organic and synthetic inorganic courses at the third-year level with those in organometallic synthesis, spectroscopy, pharmaceutical synthesis, physical organic chemistry and directed research in fourth-year. This emphasizes the impact catalysis has on contemporary synthesis and allows the undergraduate curriculum to be "greened" in a comprehensive fashion.

Encouraging Student Design and Engagement

Traditional synthetic organic laboratory experiments expect students to follow a strict protocol in order to obtain a target compound. During the spring 2006 semester, six ROP 299Y undergraduates worked on developing a new module to encourage student self-reliance during the planning stage of a synthesis, and laboratory autonomy whilst it is being undertaken. The undergraduate researchers designed an experiment which is now performed annually as the capstone experiment in Organic Synthesis Techniques. Students (up to 40 per year) are charged with synthesizing an *individualized* azlactone derivative (**12**, Scheme 3) without guidance from instructors or teaching assistants. They are provided with one of two possible starting materials and must consult relevant literature to develop a synthetic pathway towards their target molecule. This plan is checked by the instructor from safety and cost perspectives. Bonus marks are awarded for incorporation of green chemistry principles into synthetic plans (and execution of them!). Two examples of greener approaches include employment of 2-methyltetrahydrofuran as a renewable solvent and use of bismuth (III) acetate as an environmentally-benign catalyst. Most students design a three-step synthesis which is performed over two 4.5 hour laboratory periods at the end of the course. This experiment has been offered for seven years, performed by over 250 students, and has consistently been received with great enthusiasm.



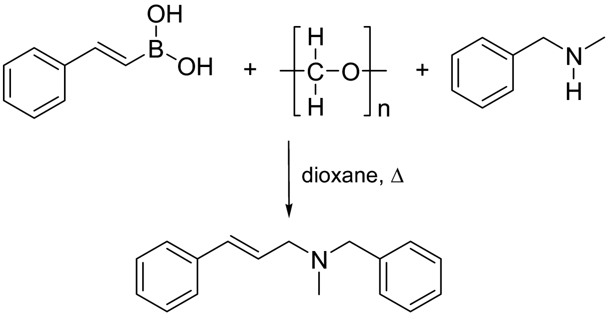
R = Me, Et

12

Scheme 3. Undergraduate-designed preparation of azlactone derivatives

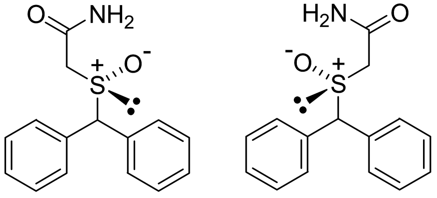
Filling Pedagogical "Holes"

An additional area of interest has been to illustrate fundamental principles by creating novel preparative experiments with little or no precedent in the pedagogical literature. One example is the synthesis of tertiary amines which has not readily been incorporated into undergraduate laboratory curricula (*30*). To rectify this, a CHM 499Y undergraduate has recently designed the microscale synthesis of *N*-benzyl-*N*-methyl-(*E*)-cinnamylamine (**13**, Scheme 4) via a Petasis reaction (*31*). This one-pot, multi-component approach combines a boronic acid, parafomaldehyde and a secondary amine to form a liquid tertiary amine. Protonation on the nitrogen atom in **13** leads to generation of a heteroatomic stereocentre, which is discernible on analysis of the ammonium salt proton NMR spectrum. A similar situation exists during the undergraduate-designed synthesis of modafinil (Provigil), a prescription anti-narcoleptic which reportedly keeps patients awake for many hours (*32*). In this experiment, an achiral sulfide is oxidized under mild reaction conditions to form the corresponding sulfoxide (2-(benzhydrylsulfinyl)acetamide (modafinil), Figure 3). This functional group transformation means the sulfur atom becomes a stereocentre and enantiomers are formed (**14 (a)** and **14 (b)**, Figure 3). The two methylene protons adjacent to the stereocentre are now diastereotopic, resonate at different chemical shifts and undergo geminal coupling. Students routinely learn in lecture that atoms other than carbon can act as stereocentres, but the concept of making and analyzing substances in the laboratory that contain *heteroatomic* stereocentres is not well-developed.



13

Scheme 4. Preparation of a tertiary amine anti-fungal analog via a Petasis reaction

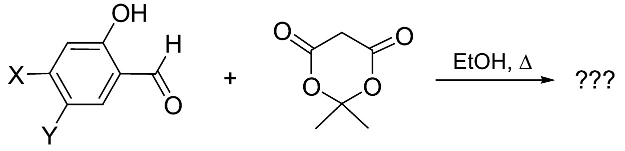


14 (a) **14 (b)**

Figure 3. Enantiomers of 2-(benzhydrylsulfinyl)acetamide (modafinil)

Discovery-Based and Collaborative/Cooperative Work

The experiments reviewed thus far in this chapter have all been incorporated into second-year or third-year synthetic courses. Undergraduates have additionally developed a number of procedures for a physical organic course, also at the third-year level (“Organic Reaction Mechanisms” (*33*)). The typical yearly enrollment of this course is between 35 and 55 students, which lends itself well to experiments that are collaborative in nature and promote cooperative learning. Firstly, students undertake an “unknown” reaction between a salicylaldehyde derivative and Meldrum's acid in ethanol solvent (Scheme 5, (*34*)). They problem-solve in small groups to try and work out mechanistic possibilities during the reaction time and submit a proposed structure to their teaching assistant after product isolation. On running a proton NMR spectrum of their obtained solid after the laboratory period, they verify that their proposal is correct or incorrect and include two potential mechanisms in their final report, justifying which one they believe to be operative.

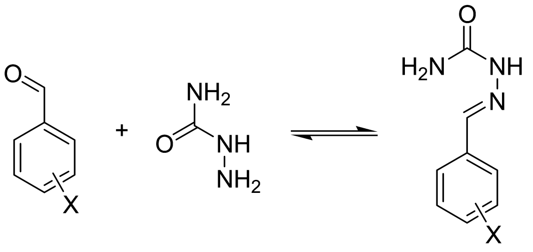


X = -N(Et)$_2$, Y = H

X = H, Y = Cl

Scheme 5. A coumarin "mystery" synthesis

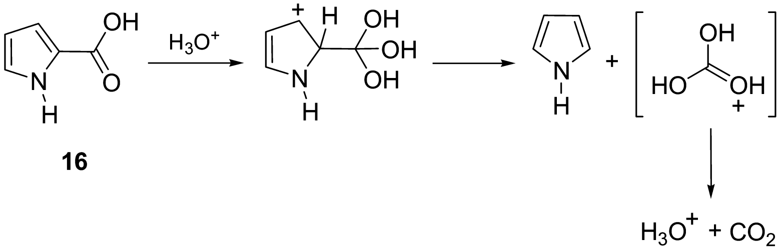
An approach that connects the lecture and laboratory aspects of the course is to have students measure pseudo-first order rate constants for a defined reaction under different conditions (e.g. varying reactant concentrations or temperature). The raw data is then pooled and made available to the whole class (via the course website) in order to construct a mechanistic plot (e.g. a free energy relationship) of some description. One system where this technique is effective is the transformation of benzaldehydes into aromatic semicarbazones (**15**, Scheme 6) on reaction with semicarbazide under acidic conditions (*35*). A class Hammett plot is obtained by students on varying substituent X in the benzaldehyde (10 - 12 derivatives) and interpreted in terms of the reaction rate-determining step.



15

Scheme 6. Semicarbazone formation from aromatic aldehydes and semicarbazide

A similar strategy is adopted for the decarboxylation of pyrrole-2-carboxylic acid (**16**, Scheme 7). Student pseudo-first order rate constant measurements under conditions of fixed [H_3O^+] and [D_3O^+] permit calculation of a solvent kinetic isotope effect. This affords an important mechanistic insight and the nature of bond-breaking in the rate-determining step (*36*). In addition, an Eyring plot is developed after making rate measurements at a variety of temperatures, which provides detail about rate-determining activation parameters (most notably ΔS‡) (*37*).



16

Scheme 7. Decarboxylation of pyrrole-2-carboxylic acid under acidic conditions

Conclusions

The variety of experimental work designed by undergraduates and profiled in this chapter has lead to a significant and exciting retooling of our departmental organic chemistry laboratory curriculum. One very noticeable aspect of working with undergraduates on pedagogically-oriented projects is their palpable enthusiasm to make a difference for future students. One may think that attracting participants would be a challenge at a research-intensive university with many other opportunities available. This has not proved to be the case and in fact the reverse is true. Teaching faculty members are “known” to many first-year students after coordinating large introductory courses, so perhaps this familiarity is advantageous when it comes to project selection. Undergraduates often have a perspective on existing laboratory manual descriptions and the nature of required practical work that faculty members do not have. In addition, the design process of (i) defining experimental learning objectives; (ii) undertaking a literature review; (iii) deciding on a starting procedure; (iv) adapting techniques for local resources, e.g. glassware and apparatus availability; (v) producing the final version for publication; and (vi) oral presentation of results is one that provides an authentic research experience. It is regularly the case that the “final” version of an experiment that reaches a laboratory manual is very different from any primary literature it was originally based upon. Similarly, manuals evolve from year to year as experiments are tweaked, feedback from students is received and new and relevant research appears.

It is worth discussing how some of the undergraduates involved in these ventures have been rewarded for their efforts and gone on to further achievements. Several have been acknowledged as oral presenters at local and national conferences. More specifically, one of them (Leo Mui) received a Chemical Education Division Undergraduate Chemistry Award for his presentation as a ROP 299Y student (“Green Syntheses of Aromatic Compounds for the Undergraduate Chemistry Laboratory”) at the 2006 Southern Ontario Universities Student Chemistry Conference (*38*). In conjunction with the university Sustainability Office, he additionally organized an ongoing campaign (Just Shut It!) to encourage departmental fume hood users to close their sashes whenever hoods are not in use. It was first run in the University of Toronto Chemistry Department during 2008-2009 (*39*). Thirdly, he recently contributed a chapter regarding alternative reaction solvents to a green chemistry teaching book ("Green Organic Chemistry in Lecture and Laboratory") (*40*, *41*). A second ROP 299Y student (Amanda Edward) wrote a chapter for the same publication (*42*). In June 2011, two CHM 499Y students (Katherine Koroluk and Liliana Guevara Opiñska) won awards for oral presentations at the 94th National Canadian Chemistry Conference in Montréal (*43*). Their presentations were entitled "Novel Petasis Reactions for the Undergraduate Organic Laboratory" and "Investigating the Mechanism of Heteroaromatic Decarboxylation: An Upper-Level Undergraduate Laboratory Experiment" respectively.

To conclude, the importance of regular laboratory curriculum renewal cannot be overstated in order to reflect current trends in chemistry research. Undergraduates are ideally positioned to take the lead in this enterprise within the framework of structured research projects. The impact of work presented here is evident in the 14 peer-reviewed publications that have ensued. In addition, designed experiments have been highlighted by the *Journal of Chemical Education* on no less than seven occasions: six times under the "Molecule of the Month" feature (*44–49*) and once as an example of medicinal interest (*50*). This recognition is a testament to the ingenuity and creativity shown by our undergraduate researchers during the last ten years.

Acknowledgments

I sincerely thank the following undergraduate students for their significant contributions in the design and implementation of all experiments described in this chapter: Evangelos Aktoudianakis, Elton Chan, Lawrence Cheung, Amanda Edward, Liliana Guevara Opiñska, Karen Jang, Isabel Jarosz, Katherine Koroluk, Vicki Lee, June Lin, Jason McIntee, Laura Minea, Leo Mui, Scott Mundle, Ryan Stabile and Sonya Thatipamala. I also acknowledge the efforts of Derek Jackson and Sarah Styler, who both participated in the Chemistry Department Teaching Fellowship Program as graduate students.

References

1. The Chemistry Department at the University of Toronto encompasses three campuses: St. George (downtown), Scarborough and Mississauga. There are a total of 52 faculty members associated with the Department. This chapter describes the structure and activities taking place at the St. George campus.
2. University of Toronto Faculty of Arts and Science Research Opportunity Program. www.artsci.utoronto.ca/current/undergraduate/course/rop (accessed Apr 25, 2012).
3. University of Toronto Chemistry Summer Research Opportunities. www.chem.utoronto.ca/undergrad/research_opportunities.php (accessed Apr 25, 2012).

4. University of Toronto CHM 499Y Research Opportunities. www.chem.utoronto.ca/undergrad/viewcourse.php?code=CHM499Y&altcode= (accessed Apr 25, 2012).
5. University of Toronto Chemistry Undergraduate Programs of Study. www.chem.utoronto.ca/undergrad/overview.php (accessed Apr 25, 2012).
6. University of Toronto Policy Regarding Teaching Stream Appointments. www.governingcouncil.utoronto.ca/Assets/Governing+Council+Digital+Assets/Policies/PDF/ppoct302003.pdf (accessed Apr 25, 2012).
7. University of Toronto Biological Chemistry Specialist Program. www.chem.utoronto.ca/undergrad/biological.php (accessed Apr 25, 2012).
8. Stabile, R. G.; Dicks, A. P. *J. Chem. Educ.* **2003**, *80*, 313–315.
9. Stabile, R. G.; Dicks, A. P. *J. Chem. Educ.* **2003**, *80*, 1439–1443.
10. Stabile, R. G.; Dicks, A. P. *J. Chem. Educ.* **2004**, *81*, 1488–1491.
11. Aktoudianakis, E.; Dicks, A. P. *J. Chem. Educ.* **2006**, *83*, 287–289.
12. Koroluk, K. J.; Skonieczny, S.; Dicks, A. P. *Chem. Educ.* **2011**, *16*, 307–309.
13. Greening the Organic Curriculum: Development of an Undergraduate Catalytic Chemistry Course. Spring 2010 ConfChem Online Conference. www.ccce.divched.org/P5Spring2010ConfChem (accessed Apr 25, 2012).
14. Lenz, R.; Ley, S. V. *J. Chem. Soc., Perkin Trans I* **1997**, 3291–3292.
15. Ley, S. V.; Ramarao, C.; Smith, M. D. *Chem. Commun.* **2001**, 2278–2279.
16. Hasan, M.; Musawir, M.; Davey, P. N.; Kozhevnikov, I. V. *J. Mol. Catal. A: Chem.* **2002**, *180*, 77–84.
17. Campestrini, S.; Carraro, M.; Ciriminna, R.; Pagliaro, M.; Tonellato, U. *Tetrahedron Lett.* **2004**, *45*, 7283–7286.
18. Kauffman, G. B.; Adloff, J.-P. *Chem. Educ.* **2011**, *16*, 51–58.
19. Aktoudianakis, E.; Chan, E.; Edward, A. R.; Jarosz, I.; Lee, V.; Mui, L.; Thatipamala, S. S.; Dicks, A. P. *J. Chem. Educ.* **2008**, *85*, 555–557.
20. Cheung, L. L. W.; Aktoudianakis, E.; Chan, E.; Edward, A. R.; Jarosz, I.; Lee, V.; Mui, L.; Thatipamala, S. S.; Dicks, A. P. *Chem. Educ.* **2007**, *12*, 77–79.
21. Liang, B.; Dai, M.; Chen, J.; Yang, Z. *J. Org. Chem.* **2004**, *70*, 391–393.
22. Dicks, A. P. *Green Chem. Lett. Rev.* **2009**, *2*, 9–21.
23. Cheung, L. L. W.; Lin, R. J.; McIntee, J. W.; Dicks, A. P. *Chem. Educ.* **2005**, *10*, 300–302.
24. Ugi, I.; Dömling, A.; Hörl, W. *Endeavour (New Series)* **1994**, *18*, 115–122.
25. Aktoudianakis, E.; Chan, E.; Edward, A. R.; Jarosz, I.; Lee, V.; Mui, L.; Thatipamala, S. S.; Dicks, A. P. *J. Chem. Educ.* **2009**, *86*, 730–732.
26. Cheung, L. L. W.; Styler, S. A.; Dicks, A. P. *J. Chem. Educ.* **2010**, *87*, 628–630.
27. U.S. Environmental Protection Agency: Twelve Principles Of Green Chemistry. www.epa.gov/sciencematters/june2011/principles.htm (accessed Apr 25, 2012).
28. Dicks, A. P. *Green Chem. Lett. Rev.* **2009**, *2*, 87–100.
29. University of Toronto Synthetic and Catalytic Chemistry Specialist Program. www.chem.utoronto.ca/undergrad/syntheticcatalytic.php (accessed Apr 25, 2012).

30. As an example, see Saba, S.; Ciaccio, J. A.; Espinal, J.; Aman, C. E. *J. Chem. Educ.* **2007**, *84*, 1011–1013.
31. Koroluk, K. J.; Jackson, D. A.; Dicks, A. P. *J. Chem. Educ.* **2012**, *89*, 796–798.
32. Aktoudianakis, E.; Lin, R. J.; Dicks, A. P. *J. Chem. Educ.* **2006**, *83*, 1832–1834.
33. University of Toronto Organic Reaction Mechanisms. www.chem.utoronto.ca/undergrad/viewcourse.php?code=CHM348F&altcode= (accessed Apr 25, 2012).
34. Minea, L. M.; Dicks, A. P. *Chem. Educ.* **2009**, *14*, 105–107.
35. Ikeda, G. K.; Jang, K.; Mundle, S. O. C.; Dicks, A. P. *J. Chem. Educ.* **2006**, *83*, 1341–1343.
36. Mundle, S. O. C.; Guevara Opiñska, L.; Kluger, R.; Dicks, A. P. *J. Chem. Educ.* **2011**, *88*, 1004–1006.
37. Mundle, S. O. C.; Lacrampe-Couloume, G.; Sherwood Lollar, B.; Kluger, R. *J. Am. Chem. Soc.* **2010**, *132*, 2430–2436.
38. 34th Southern Ontario Universities Student Chemistry Conference, York University, Ontario, Canada. www.chem.yorku.ca/SOUSCC/awards.htm (accessed Apr 25, 2012).
39. University of Toronto Just Shut It! Sustainability Campaign. http://sustainability.utoronto.ca/projects/past/fumehoods/justshutit/justshutitguide.htm (accessed Apr 25, 2012).
40. Mui, L. Organic Chemistry in Greener Non-Aqueous Media. In *Green Organic Chemistry in Lecture and Laboratory*; Dicks, A. P., Ed.; CRC Press: Boca Raton, FL, 2012; pp 131−164.
41. Dicks, A. P., Ed. *Green Organic Chemistry in Lecture and Laboratory*, CRC Press: Boca Raton, FL, 2012.
42. Edward, A. R. Organic Waste Management and Recycling. In *Green Organic Chemistry in Lecture and Laboratory*; Dicks, A. P., Ed.; CRC Press: Boca Raton, FL, 2012; pp 199−224.
43. 94th Canadian Chemistry Conference and Exhibition Student Award Winners. www.csc2011.ca/Program/Student_Competition_Winners.pdf (accessed Apr 25, 2012).
44. Wildman, R. J.; Coleman, W. F. *J. Chem. Educ.* **2003**, *80*, 315.
45. Coleman, W. F. *J. Chem. Educ.* **2003**, *80*, 1496.
46. Coleman, W. F. *J. Chem. Educ.* **2004**, *81*, 1491.
47. Coleman, W. F. *J. Chem. Educ.* **2008**, *85*, 592.
48. Coleman, W. F. *J. Chem. Educ.* **2009**, *86*, 768.
49. Coleman, W. F. *J. Chem. Educ.* **2010**, *87*, 654–655.
50. Clauss, A. W. *J. Chem. Educ.* **2008**, *85*, 1657.

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

Chapter 3

Fluorophores, Fluorescent Polymers, and Energy Transfer in an Undergraduate Laboratory Setting

Mindy Levine* **and Patrick Marks**

Department of Chemistry, University of Rhode Island,
51 Lower College Road, Kingston, RI 02881
***mlevine@chm.uri.edu**

Organic fluorophores are rarely synthesized at the undergraduate level, often because of the tedious procedures required for their synthesis. One example of such fluorophores, squaraines, are a class of near-infrared emitting fluorophores with unique photophysical properties. Squaraines are often synthesized via the condensation of an electron-rich aniline with squaric acid, refluxed overnight in a mixed solvent system. Reported herein are the syntheses of a variety of organic fluorophores in an undergraduate laboratory setting, including modifications to the literature-reported synthesis of a particular squaraine molecule that allowed it to be synthesized at the undergraduate level. The photophysical properties of these fluorophores can also be analyzed. Finally, the fluorophores can be used for a variety of interesting applications, including the fabrication of hybrid thin films and nanoparticles with fluorescent conjugated polymers.

Introduction

Historically, experiments for the undergraduate organic teaching laboratory have generally fallen into one of two categories: (a) laboratories that teach techniques, such as extraction, distillation, or recrystallization (*1*); or (b) simple one-step syntheses, such as the synthesis of ibuprofen (*2*), creatine (*3*), or bisphenol Z (*4*).

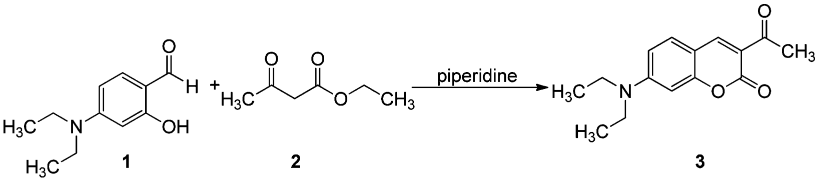
Over the past several decades, there have been substantial modifications to the undergraduate organic laboratory curriculum (*5*). For example, the scale of

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

the reactions has generally decreased (*6–9*), which results in decreased material costs as well as decreased waste production. Students are also being exposed to a great variety of modern instrumentation, including high performance liquid chromatography (HPLC) (*10*, *11*) and gas chromatography-mass spectrometry (GC-MS) (*12*, *13*), and many are learning how to use microwaves to facilitate organic synthesis (*14*, *15*).

Undergraduates are also increasingly being introduced to topics that are prevalent in the research laboratory (*16–20*). For example, a variety of undergraduate-friendly experiments have been designed in the field of organocatalysis (*21*, *22*) as well as in the field of metal-catalyzed cross-coupling chemistry (*23*, *24*).

Despite these significant advances, there have been only a few examples of the synthesis of organic fluorescent dyes in an undergraduate teaching laboratory (*25*). For example, coumarin dye **3** was synthesized on a microscale via the Knoevenagel condensation (*26*) of 4-(diethylamino)salicylaldehyde **1** and ethyl acetoacetate **2** (Equation 1) (*27*).

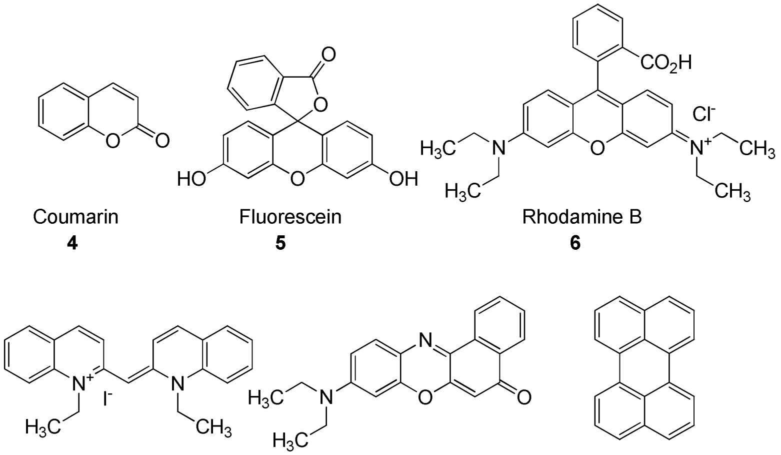


*Equation 1: Microscale synthesis of coumarin dye **3***

There have been a few examples of the synthesis of fluorophores in an inorganic (*28*, *29*) or materials science teaching laboratory (*30*). The dearth of organic fluorophores at the undergraduate level occurs despite the fact that organic fluorescent dyes have been well-studied in research laboratories (*31–34*). A number of commercially available organic fluorophores are shown in Chart 1.

In addition to commercially available organic fluorophores, other fluorophores can be synthesized via straightforward synthetic procedures. One example, near-infrared emitting fluorophores, are of particular interest for biological applications, as the near-infrared spectral region has little interference from other biological analytes (*35*). Near-infrared light also demonstrates deeper tissue penetration compared to shorter wavelength light (*36*).

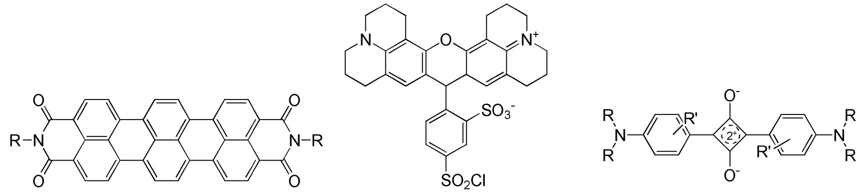
Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003



Coumarin **4**
Fluorescein **5**
Rhodamine B **6**
1,1'-Diethyl-2,2'-cyanine iodide **7**
Nile Red **8**
Perylene **9**

Chart 1. Examples of commercially available fluorophores

Some examples of near-infrared emitting fluorophores are shown in Chart 2.

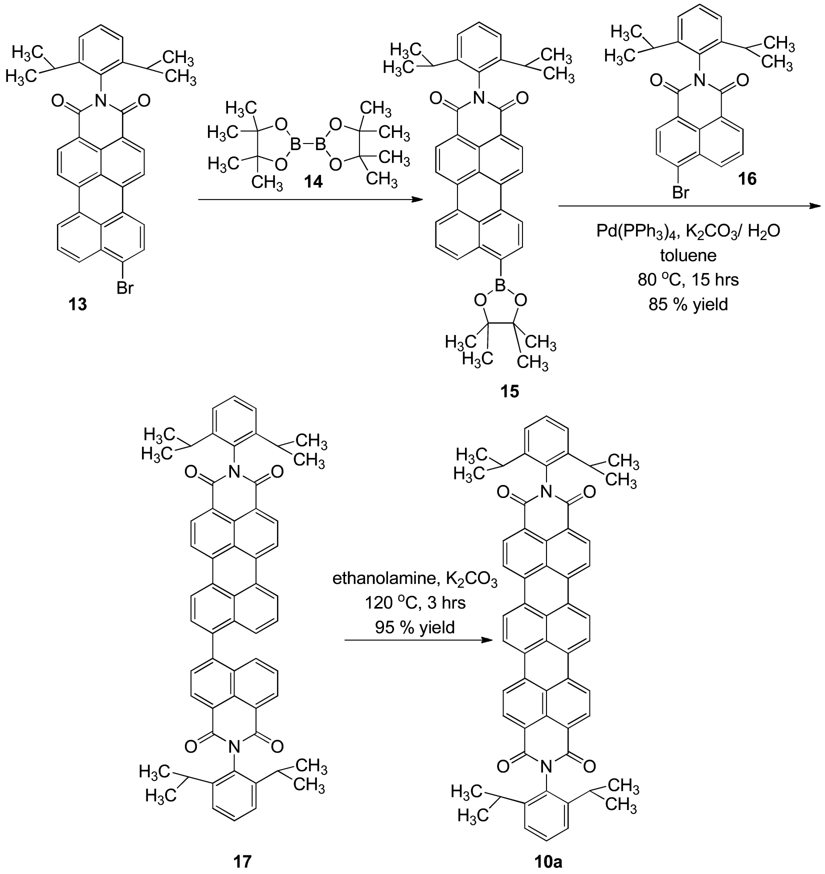


Terrylenes **10**
Texas Red **11**
Squaraines **12**

Chart 2. Examples of near-infrared emitting fluorophores

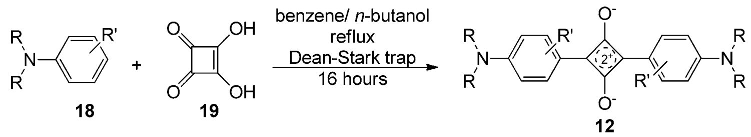
Terrylene diimides (compound **10**) (*37*) are typically synthesized in several steps that are air- and moisture-sensitive (Scheme 1) (*38*). Such multi-step synthetic procedures are generally impractical in an undergraduate laboratory setting.

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003


13
14
15
16
Pd(PPh3)4, K2CO3/ H2O
toluene
80 °C, 15 hrs
85 % yield
17
10a
ethanolamine, K2CO3
120 °C, 3 hrs
95 % yield

Scheme 1. Synthesis of terrylene diimides

In contrast, squaraines are typically synthesized in one step via the condensation of squaric acid with electron-rich aniline compounds (Equation 2), and some squaraines that have been synthesized via this reaction are shown in Chart 3 (*39–45*).


18
19
benzene/ n-butanol
reflux
Dean-Stark trap
16 hours
12

Equation 2: Synthesis of symmetrical squaraine dyes

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

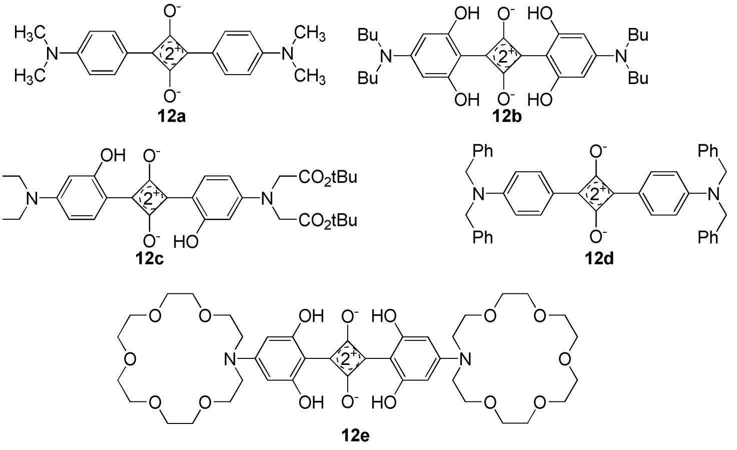


*Chart 3. Examples of symmetrical squaraines synthesized by the condensation of squaric acid **19** with electron-rich anilines*

Squaraines have narrow absorption and emission bands, often in the near-infrared region (*46–49*). Squaraines can be used for the fluorescent-based sensing of a variety of metal ions (*50–53*) and thiols (*54*), as well as for biological imaging (*55*, *56*). Squaraines have also been used as energy acceptors in a variety of energy transfer schemes (*57–59*). In one such scheme, squaraine **12a** was used as an energy acceptor in conjunction with a polyphenyleneethynylene energy donor (compound **20**). Up to 100-fold amplification of fluorescence was observed from exciting the polymer compared to exciting the fluorophore directly (Figure 1) (*60*).

Despite the ubiquitous nature of squaraines in the research laboratory, squaraines have not been synthesized in an undergraduate laboratory setting (*61*). A Scifinder search of "squaraine and chemical education," "squaraine and undergraduates," and "squaraine and teaching laboratory," yielded no papers (and only one conference abstract). This is likely due to the long reaction times reported for the synthesis of squaraines. These syntheses are typically performed by refluxing the reactants overnight in a mixed solvent system (either benzene/*n*-butanol (*62*, *63*) or isopropanol/tri-*n*-butyl orthoformate) (*64*, *65*). Reported herein are the syntheses of a variety of organic fluorophores in the teaching laboratory, including adaptations to the synthesis of a squaraine dye that allowed it to be performed in an undergraduate laboratory.

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

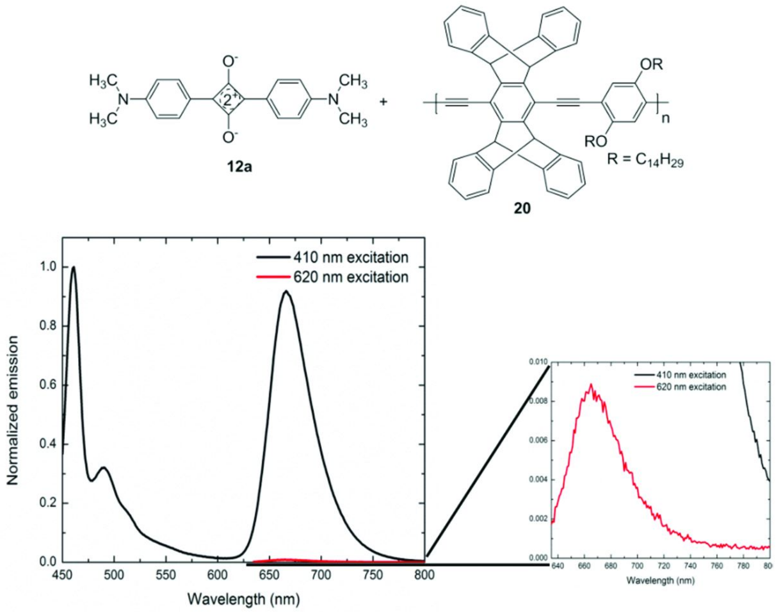


*Figure 1. Energy transfer between polyphenyleneethynylene **20** and squaraine dye **12a***

Practical Synthesis of a Squaraine Dye

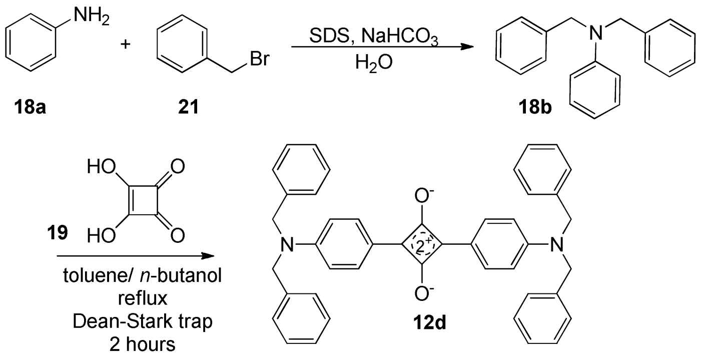
Overview

We have recently developed an improved procedure that allows squaraines to be synthesized in an advanced undergraduate laboratory (*61*). In this procedure, a 12 hour reflux in a benzene/*n*-butanol mixture has been replaced by a two hour reflux in toluene/*n*-butanol. The dibenzyl-functionalized squaraine **12d** was synthesized in two steps (Scheme 2).

Each step was conducted in a four-hour laboratory session with advanced chemistry majors, and the students, working individually, learned a variety of chemistry from each synthetic step. In a third laboratory period, students were able to analyze the absorbance and fluorescence properties of the newly synthesized squaraine dye.

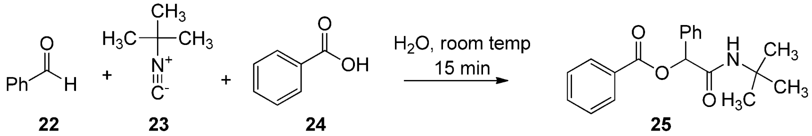
Synthesis Step 1

The first step, the synthesis of dibenzylaniline **18b**, occurs in an aqueous solvent system in the presence of sodium dodecyl sulfate (SDS). The SDS acts to form micelles that sequester the organic reactants, with the actual reaction occurring inside the micelles. This reaction represents an example of green chemistry, because it occurs in a benign aqueous solvent rather than more toxic organic solvents (*66*).


NH2
Br
SDS, NaHCO3
H2O
N
18a
21
18b
HO
O
HO
O
19
toluene/ n-butanol
reflux
Dean-Stark trap
2 hours
N
O-
2+
O-
N
12d

Scheme 2. Synthesis of squaraine ***12d*** *via a two-step procedure*

There are other reported examples where undergraduate students have conducted organic reactions in water (*67*). In one such example, a multi-component Passerini reaction was conducted in water (Equation 3) (*68*). Compound **25** was formed in 15 minutes, which represented a substantial rate enhancement (*69*, *70*) compared to Passerini reactions performed in typical organic solvents (*71*).


O
Ph
H
22
CH3
H3C
CH3
N+
C-
23
O
OH
24
H2O, room temp
15 min
O
Ph
O
O
H
N
CH3
CH3
H3C
25

Equation 3: Synthesis of compound ***25*** *via a multi-component Passerini reaction*

The aqueous Passerini reaction represents an example of the well-documented beneficial effect of water on organic reactions. The addition of water generally causes hydrophobic reactants to aggregate in an attempt to minimize their contact with water (*72–74*), which can lead to proximity-induced rate accelerations (*75*, *76*).

In the particular reaction discussed herein (alkylation of aniline **18a** with benzyl bromide **21**), researchers investigated the synthesis of a variety of

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

di-substituted anilines in an aqueous solvent system (*77*). They found that using an aqueous solvent conferred a number of operational advantages, including a rapid reaction, ease of purification, and absence of quarternary ammonium byproducts. The desired product **18b** was synthesized in a nearly quantitative yield. Analogous acylation reactions of amines in water were also reported (*78*). Because dibenzylaniline **18b** is a commercially available, relatively inexpensive compound, instructors can skip this synthetic step and move directly to the synthesis of the squaraine (step 2)

Synthesis Step 2

The second step in the synthesis is the condensation of dibenzylaniline **18b** with squaric acid to yield squaraine product **12d**. Compound **12d** has been synthesized previously, with the literature-reported procedure requiring a 12 hour reflux in a benzene/*n*-butanol solvent system to obtain the desired squaraine in 35% yield (*42*). We found that a two-hour reflux in toluene/*n*-butanol provided the desired product in comparable yields, ranging from 8-35% for undergraduate students. The product crystallized spontaneously from the reaction mixture upon cooling to yield bright green crystals.

This step provides a myriad of pedagogical opportunities. In particular, squaraines have a unique electron-deficient cyclobutene core. One resonance form for the squaraine puts a +2 charge on the central ring, with each of the oxygens carrying a negative charge (*79*, *80*). This unusual zwitterionic core benefits from the aromatic stability of the cyclobutene (4n+2 with n=0). Although undergraduate chemistry majors have learned about aromaticity, that discussion will likely have focused predominantly on benzene as a prototypical aromatic molecule. The synthesis of an aromatic squaraine compound will provide a key opportunity to discuss other aromatic compounds with unusual structures. Some examples of such structures, including charged aromatic compounds, are shown in Chart 4 (*81*, *82*).

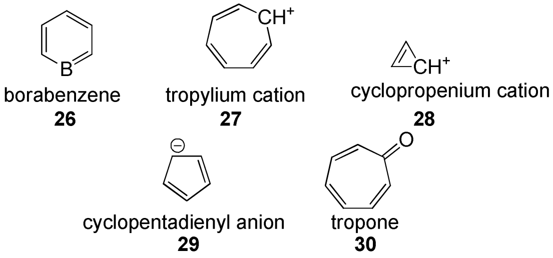
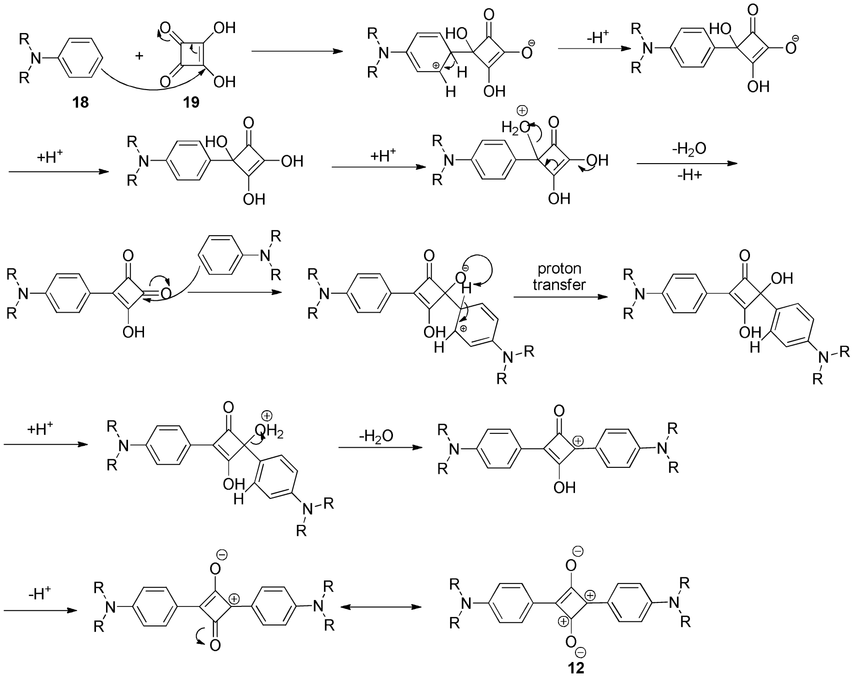


Chart 4. Examples of unusual aromatic compounds

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

The presumed mechanism of squaraine formation is shown in Scheme 3.

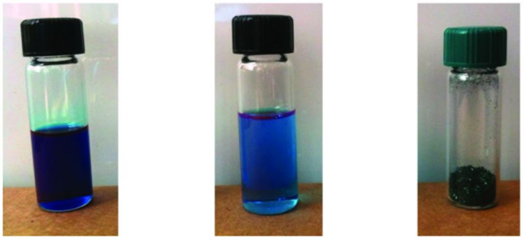


Scheme 3. Mechanism for the synthesis of squaraine compounds

Photophysical Analysis

The newly synthesized squaraine **12d** crystallizes as bright green crystals. Concentrated solutions of the squaraine appear red, and dilute solutions appear bluish-red (Figure 2). The different colors are determined by the extent of squaraine aggregation: due to their extended planar core, squaraine molecules have a tendency to form aggregates in solution (*83*, *84*). These aggregates have a shorter wavelength absorption, which can be seen as a shoulder in the visible absorption spectrum around 570 nm (Figure 3), and corresponds to a reddish color. Dilute solutions, by contrast, display limited aggregation, and therefore show a narrow peak in the visible absorption spectrum.

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003



Concentrated solution

Dilute solution

Solid crystals

*Figure 2. Color of squaraine **12d** under various conditions. (reprinted from the supporting information of Reference (61))*

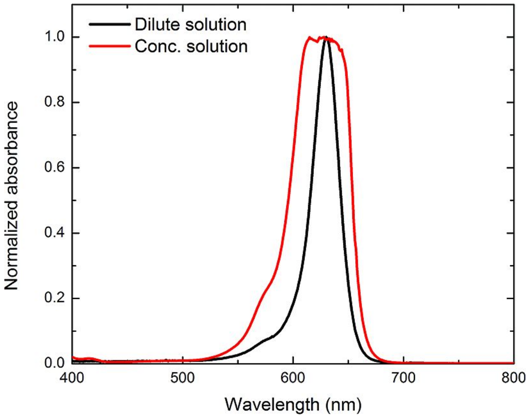


*Figure 3. Normalized visible spectra of dilute and concentrated solutions of squaraine **12d***

Other Notes on the Synthesis

The reported synthesis of squaraine compound **12d** has a number of other features that make it particularly amenable for an undergraduate laboratory.

(1) Both steps of the synthesis tolerate some degree of air and moisture. The first step of the reaction occurs in water. The second step of the reaction utilizes a Dean-Stark trap to remove water as it is formed. Practically, this means that small amounts of water will not interfere with the desired reaction, as the water will simply be removed in the Dean-Stark trap.

(2) With the exception of squaric acid, the cost of the required chemicals is modest. We typically ran this reaction on a 300-500 mg scale, which allowed the crystals of dibenzylaniline (compound **18b**) to be easily isolated. The cost of the required chemicals (if purchased from Sigma-Aldrich; prices as of May 2012) is as follows:

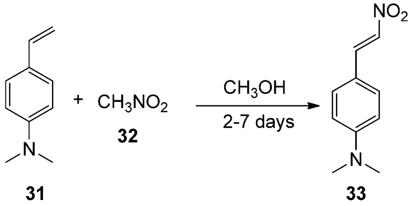
- (a) aniline (\$47.80 for 500 mL; \$0.09/gram)
- (b) benzyl bromide (\$41.30 for 100 grams; \$0.41/gram)
- (c) sodium dodecyl sulfate (\$32.50 for 25 grams; \$1.30/gram)
- (d) squaric acid (\$178 for 25 grams; \$7.12/gram)
- (e) sodium bicarbonate (\$36.70 for 500 grams; \$0.07/gram)

(3) Even if squaraine **12d** does not spontaneously crystallize, and the final squaraine product is not cleanly formed, in many cases students can still observe the desired photophysical properties. If the squaraine did not crystallize, students simply removed the solvent on the rotary evaporator to obtain an amorphous green solid that was sufficiently pure for the visible and fluorescence experiments. Moreover, students require only a few milligrams of squaraine **12d** to obtain visible and fluorescence spectra (because of the squaraine's high molar absorptivity coefficient and quantum yield). Practically, students were able to obtain yields as low as 8% for the second step of the synthesis, and still obtain good quality photophysical spectra.

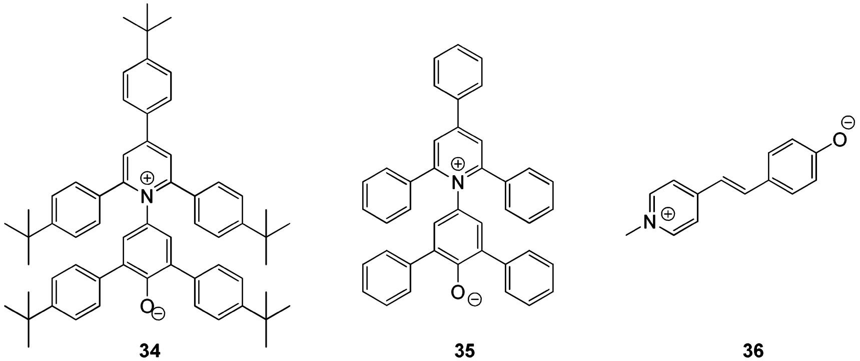
Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

Practical Synthesis of Other Fluorophores

Some examples of other organic fluorophores have also been synthesized at the undergraduate level. In one case, 1-(*p*-dimethylaminophenyl)-2-nitroethylene **33** was synthesized from the Henry reaction of p-dimethylaminobenzaldehyde and nitromethane (Equation 4) (*25*). This highly solvatochromic dye (*85*) shows a 32-fold increase in fluorescence in a toluene solution compared to its fluorescence in dimethylsulfoxide, and provides an opportunity to teach students about solvatochromism and its potential applications in biological detection schemes (*86*). Other examples of solvatochromic dyes used at the undergraduate level are shown in Chart 5. They include compound **34** that was used to monitor the composition of biofuel (*87*), and Reichardt's dye (compound **35**) (*88*) and Brooker's merocyanine (compound **36**) (*89*) that were used to demonstrate solvent polarity (*90*).



*Equation 4: Synthesis of solvatochromic dye **33** via a Henry reaction*



34 **35** **36**

Chart 5. Other examples of solvatochromic dyes used at the undergraduate level

Organometallic fluorophores have also been synthesized in the undergraduate laboratory setting. In particular, Al(III)(8-hydroxyquinolinolato)$_3$ and Eu(III)(thenoyltrifluoroacetonato)3(1,10-phenanthroline) were synthesized in one-step, high-yielding reactions (*28*). Other examples of fluorophores studied in the undergraduate laboratory include formazan dyes (*91*), which consist of stable radicals, and a variety of phosphorescent fluorophores (*92–94*).

Applications of the Fluorophores

The newly synthesized fluorophores can be used for a number of applications, many of which are adaptable for an undergraduate teaching laboratory.

Thin Film Formation

Thin films can be fabricated using the newly synthesized squaraine **12d** (or any of the other organic fluorophores) in combination with either an inert polymer (like polymethylmethacrylate) or a fluorescent conjugated polymer (such as polyphenyleneethynylene). A spin-coater is required to fabricate these films, such as a WS-400-6NPP model from Laurell Technologies. While these coaters cost an average of $3000, they are extremely robust and can be used for a number of years. Alternatively, a simple fan can act as an inexpensive spin coater, following literature reports that use a fan to fabricate polystyrene thin films (Figure 4) (*95*). There have been other reported examples of fabricating thin films in an undergraduate laboratory setting, mostly via dip coating followed by subsequent annealing (*96*, *97*).

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

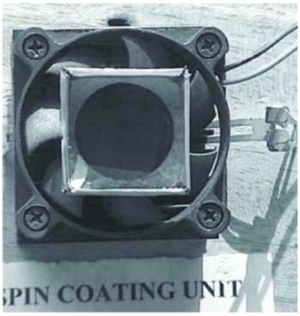


Figure 4. A picture of a cooling fan used as an inexpensive spin coater. (reprinted from reference (95))

Films fabricated with the inert polymer and squaraine **12d** will lead to a change in the photophysical properties of squaraine in the solid state (weaker and broader emission; blue-shifted absorption maximum) (*98–100*). For the conjugated polymer-fluorophore films, students can synthesize the conjugated polymer in a separate laboratory exercise (see below). Alternatively, a variety of conjugated polymers can be purchased (Chart 6).

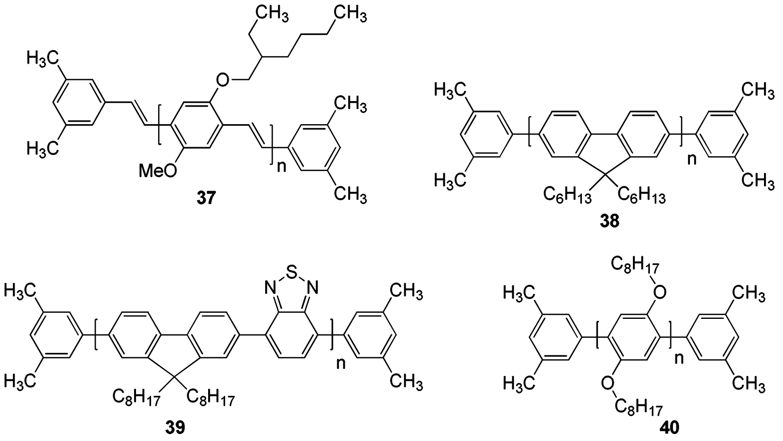


Chart 6. Examples of commercially available conjugated polymers. (source: ADS Dyes, www.adsdyes.com)

In the thin films that contain a conjugated polymer and squaraine **12d**, students will be able to study the energy transfer between the polymer and the squaraine. In these films, excitation of the polymer will lead to energy transfer to and emission from the dye (Figure 5).

This emission will be amplified compared to the emission observed from directly exciting the dye, as a result of the ability of the conjugated polymers to act as amplifying molecular wires (Figure 6) (*101*). Such energy transfer has been studied by a number of research groups (*102–105*). Researchers have found that energy transfer between a non-covalently attached donor and acceptor generally requires the molecules to be confined in close proximity, either in thin films or in hybrid nanoparticles (see application 2, below) (*106*, *107*).

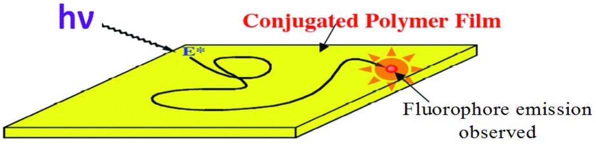

hν
Conjugated Polymer Film
E*
Fluorophore emission observed

Figure 5. Illustration of energy transfer in polymer-squaraine hybrid thin films. (reprinted from ref (101))

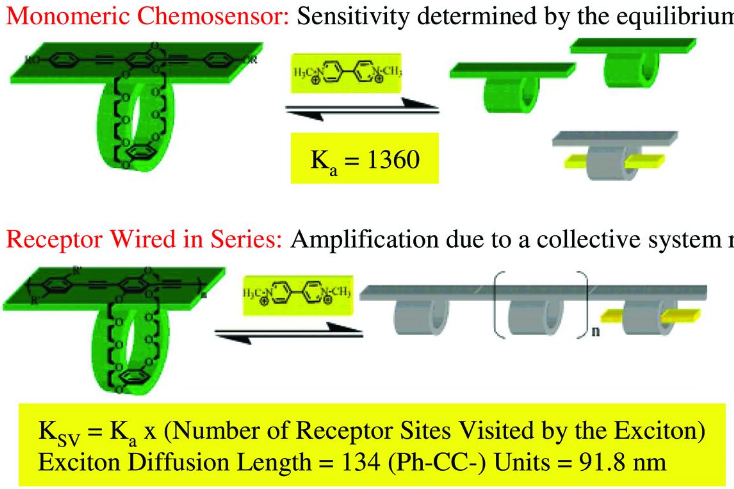

Monomeric Chemosensor: Sensitivity determined by the equilibrium constant
K_a = 1360
Receptor Wired in Series: Amplification due to a collective system response
n
K_{SV} = K_a x (Number of Receptor Sites Visited by the Exciton)
Exciton Diffusion Length = 134 (Ph-CC-) Units = 91.8 nm

Figure 6. Illustration of amplification of fluorescence that occurs with conjugated polymers. (reprinted from ref (101))

Nanoparticle Fabrication:

Nanoparticles that contain the newly synthesized dyes can be fabricated using the re-precipitation method (*108*, *109*), with either an inert polymer host or a

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

fluorescent conjugated polymer. The procedure to fabricate such particles involves the slow addition of a squaraine/polymer solution in THF to a sonicating aqueous solution. In the nanoparticles formed with a conjugated polymer and squaraine, students can study energy transfer (analogous to the thin-film energy transfer), with excitation of the polymer resulting in amplified squaraine emission (Figure 7). Previous research has found up to 50-fold amplification of squaraine fluorescence from excitation of the polymer compared to exciting the squaraine directly (Figure 8) (*110*).

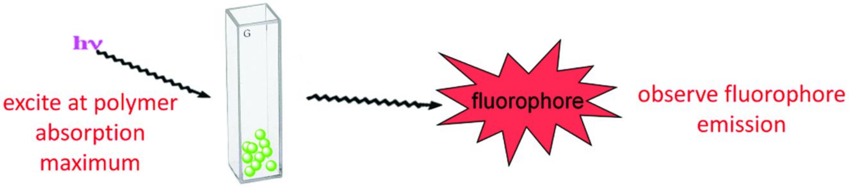

hν
excite at polymer absorption maximum
G
fluorophore
observe fluorophore emission

Figure 7. Schematic of energy transfer in hybrid nanoparticles

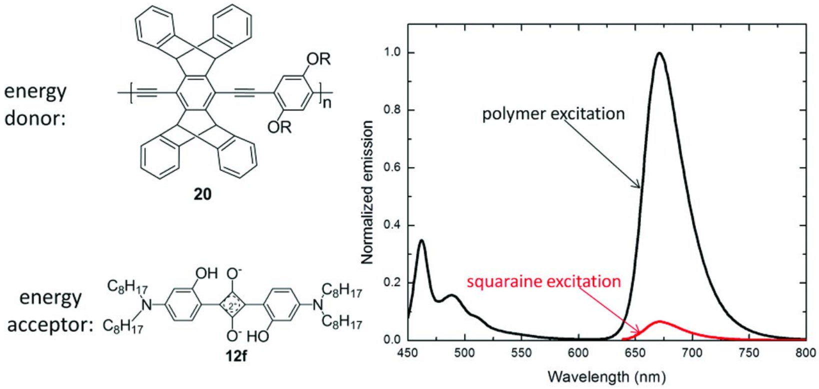


Figure 8. Example of highly efficient energy transfer in hybrid nanoparticles

The only equipment required for nanoparticle fabrication is a sonicator, such as a Branson 3150 model (approximately $700), although a visible spectrometer and fluorimeter will be required to study the energy transfer. One inexpensive option is for students to use a MicroLab spectrometer (www.microlabinfo.com) to measure the photophysical properties of the nanoparticle solutions (*111*).

Jason McNeill and co-workers have formed similar hybrid nanoparticles with a conjugated polymer donor and small-molecule acceptor (Chart 7) (*112*).

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

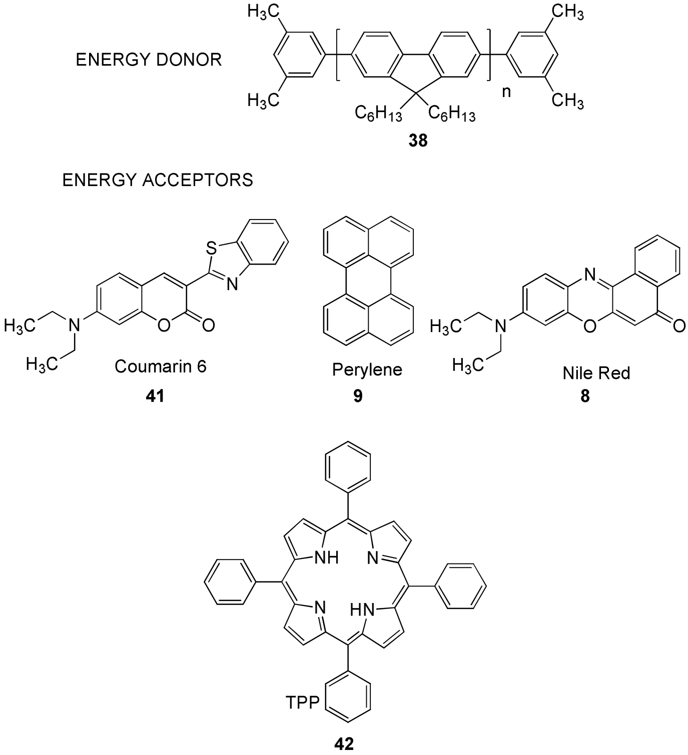

ENERGY DONOR
H_3C
CH_3
H_3C
CH_3
C_6H_{13}
C_6H_{13}
n
38
ENERGY ACCEPTORS
S
N
H_3C
N
O
O
H_3C
Coumarin 6
41
Perylene
9
N
H_3C
N
O
O
H_3C
Nile Red
8
NH
N
N
HN
TPP
42

Chart 7. Compounds used for energy transfer experiments in hybrid nanoparticles

Up to a 40% relative quantum yield was observed for particles with 2% of coumarin **41** or perylene **9** in polymer **38**. Similar blended nanoparticles were also formed with two different conjugated polymers, in which energy transfer occurred from the blue-emitting polyfluorene to a red-emitting polymer acceptor (Figure 9) (*108*).

Nanotechnology has become increasingly prevalent in the chemical industry, with applications ranging from drug delivery (*113*) to bioimaging (*114*) and solar cell fabrication (*115*). Introducing undergraduate students to the field of nanotechnology (*116*, *117*) and the ease with which nanoparticles can be fabricated will help to prepare them for industry jobs post-graduation.

PF = polyfluorene, PFPV = polyfluorene-alt-polyphenylenevinylene; PFBT = polyfluorene-alt-polybenzothiadiazole; MEH-PPV = poly[2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene].

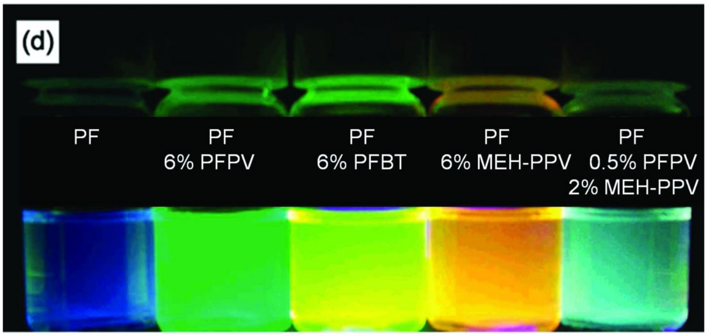


Figure 9. Photograph of fluorescence emission from aqueous suspensions of the blend nanoparticles taken under a UV lamp (365 nm). (Reprinted from ref (108).) (see color insert)

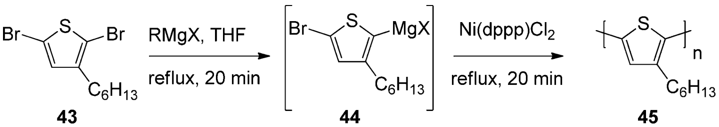
Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

Energy Transfer Inside Cyclodextrins

The newly synthesized squaraine **12d** can also be used as an energy acceptor in combination with a small-molecule energy donor bound inside a γ-cyclodextrin cavity. In particular, we have found that anthracene and squaraine will bind in γ-cyclodextrin simultaneously (*118*, *119*). Excitation of the resulting ternary complex at 360 nm (near the anthracene absorption maximum) resulted in energy transfer to and emission from the squaraine molecule. Up to 30% emission was observed from indirect excitation of the squaraine compared to directly exciting the squaraine at 620 nm. γ-cyclodextrin is known to be able to form ternary complexes with two different guests simultaneously (*120*, *121*), although to the best of our knowledge, energy transfer inside a cyclodextrin cavity has not yet been demonstrated.

Synthesis of Conjugated Polymers

For many of the energy transfer applications discussed herein, a fluorescent conjugated polymer is required. Such polymers can be purchased from commercial sources (such as ADS Dyes), although they are often quite costly. Some examples of the synthesis of fluorescent polymers in an undergraduate laboratory have been reported (*122*, *123*). In one case, poly-3-hexythiophene was synthesized via the Grignard polymerization of monomer **43** (Equation 5). Anhydrous conditions and an inert nitrogen atmosphere were required to obtain optimal yields (*122*). Alternatively, conducting polymers can be synthesized via electrochemical polymerization, which eliminates some of the requirements for strictly inert reaction condition (*124*).



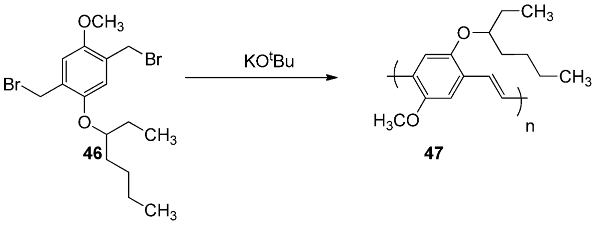
43 **44** **45**

*Equation 5: Synthesis of polymer **45** via Grignard polymerization*

Students can also synthesize polymethylmethacrylate using a procedure developed for an undergraduate laboratory (*125*). This reaction uses 2,2′-azobis(2-methylpropionitrile) (AIBN) as a radical initiator, in combination with methyl methacrylate (MMA) as the active monomer.

Despite these precedents for the synthesis of conjugated polymers in an undergraduate laboratory setting, work is still needed to identify a truly robust synthetic sequence, which will yield a polymer that can act as an efficient energy donor. Efforts towards this goal are currently underway in our laboratory. Preliminary experiments have shown that the Gilch-type polymerization of monomer **46** yields a bright red fluorescent polymer in good yields (Equation 6) (*126–128*). This reaction was performed by several students in an undergraduate laboratory, without the rigorous exclusion of oxygen or moisture.

Once an optimal synthetic sequence has been identified, the newly synthesized polymers must still be tested for their ability to act as energy donors in combination with a small-molecule fluorophore acceptor. Literature precedent indicates that polymers with bulky side chains and/or main chains can act as more efficient energy donors than planar polymers, because the steric bulk prevents the polymer from aggregating and allows the fluorophore to bind in close proximity to the conjugated polymer backbone (*129*).



46 **47**

*Equation 6: Synthesis of fluorescent polymer **47***

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

Summary and Conclusions

Reported herein are straightforward procedures to synthesize a variety of fluorophores in an undergraduate laboratory setting. This procedure provides several teaching opportunities, including a discussion of green chemistry as well as the structures of unusual aromatic compounds. Once synthesized, the fluorophores can be incorporated into thin films and nanoparticles, and their properties as fluorescent energy acceptors can be explored. Many of the applications of the newly synthesized dyes teach key techniques (thin film formation, nanoparticle fabrication) that will be invaluable for students post-graduation. Moreover, this experiment can be considered truly interdisciplinary, as it combines several key areas of chemical education, including organic synthesis, fluorescence, and material and device fabrication.

References

1. Horowitz, G. *J. Chem. Educ.* **2003**, *80*, 1039–1041.
2. Kjonaas, R. A.; Williams, P. E.; Counce, D. A.; Crawley, L. R. *J. Chem. Educ.* **2011**, *88*, 825–828.
3. Smith, A. L.; Tan, P. *J. Chem. Educ.* **2006**, *83*, 1654–1657.
4. Gregor, R. W. *J. Chem. Educ.* **2012**, *89*, 669–671.
5. Martin, C. B.; Schmidt, M.; Soniat, M. *J. Chem. Educ.* **2011**, *88*, 1630–1638.
6. DeMott, J. M., Jr.; Kelly, C. J. *J. Chem. Educ.* **2001**, *78*, 780.
7. O’Connor, K. J.; Zuspan, K.; Berry, L. *J. Chem. Educ.* **2011**, *88*, 325–327.
8. Crouch, R. D.; Holden, M. S. *J. Chem. Educ.* **2002**, *79*, 477–478.
9. Fuhry, M. A. M.; Colosimo, C.; Gianneschi, K. *J. Chem. Educ.* **2001**, *78*, 949–950.
10. Lee, I.; Boyce, M. C. *J. Chem. Educ.* **2011**, *88*, 832–834.
11. Leacock, R. E.; Stankus, J. J.; Davis, J. M. *J. Chem. Educ.* **2011**, *88*, 232–234.
12. Mead, R. N.; Seaton, P. J. *J. Chem. Educ.* **2011**, *88*, 1130–1132.
13. Clennan, M. M.; Clennan, E. L. *J. Chem. Educ.* **2011**, *88*, 646–648.
14. Horta, J. E. *J. Chem. Educ.* **2011**, *88*, 1014–1015.
15. Baar, M. R.; Falcone, D.; Gordon, C. *J. Chem. Educ.* **2010**, *87*, 84–86.
16. Enders, D.; Balensiefer, T. *Acc. Chem. Res.* **2004**, *37*, 534–541.
17. Pellissier, H. *Adv. Synth. Catal.* **2012**, *354*, 237–294.
18. List, B. *Chem. Commun.* **2006**, 819–824.
19. Narayanan, R. *Molecules* **2010**, *15*, 2124–2138.
20. Seidel, G.; Fuerstner, A. *Chem. Commun.* **2012**, *48*, 2055–2070.
21. Wade, E. O.; Walsh, K. E. *J. Chem. Educ.* **2011**, *88*, 1152–1154.
22. Lazarski, K. E.; Rich, A. A.; Mascarenhas, C. M. *J. Chem. Educ.* **2008**, *85*, 1531–1534.
23. Callam, C. S.; Lowary, T. L. *J. Chem. Educ.* **2001**, *78*, 947–948.
24. Pantess, D. A.; Rich, C. V. *Chem. Educ.* **2009**, *14*, 258–260.
25. Richter-Egger, D. L.; Tesfai, A.; Flamm, S. J.; Tucker, S. A. *J. Chem. Educ.* **2001**, *78*, 1375–1378.
26. Toure, B. B.; Hall, D. G. *Chem. Rev.* **2009**, *109*, 4439–4486.

27. Aktoudianakis, E.; Dicks, A. P. *J. Chem. Educ.* **2006**, *83*, 287–289.
28. Liu, Q.; Wang, S. *J. Chem. Educ.* **2003**, *80*, 1474–1475.
29. Bolstad, D. B.; Diaz, A. L. *J. Chem. Educ.* **2002**, *79*, 1101–1104.
30. Degli Esposti, C.; Bizzocchi, L. *J. Chem. Educ.* **2008**, *85*, 839–841.
31. Escobedo, J. O.; Rusin, O.; Lim, S.; Strongin, R. M. *Curr. Opin. Chem. Biol.* **2010**, *14*, 64–70.
32. Baumes, J. M.; Gassensmith, J. J.; Giblin, J.; Lee, J.-J.; White, A. G.; Culligan, W. J.; Leevy, W. M.; Kuno, M.; Smith, B. D. *Nature Chem.* **2010**, *2*, 1025–1030.
33. Kwon, J. E.; Park, S. Y. *Adv. Mater.* **2011**, *23*, 3615–3642.
34. Shimizu, M.; Hiyama, T. *Chem. Asian J.* **2010**, *5*, 1516–1531.
35. Weissleder, R. *Nature Biotechnol.* **2001**, *19*, 316–317.
36. Frangioni, J. V. *Curr. Opin. Chem. Biol.* **2003**, *7*, 626–634.
37. Rodriguez-Hernadez, J.; Qu, J.; Reuther, E.; Klok, H.-A.; Muellen, K. *Polym. Bull.* **2004**, *52*, 57–64.
38. Nolde, F.; Qu, J.; Kohl, C.; Pschirer, N. G.; Reuther, E.; Muellen, K. *Chem. Eur. J.* **2005**, *11*, 3959–3967.
39. Snee, P. T.; Somers, R. C.; Nair, G.; Zimmer, J. P.; Bawendi, M. G.; Nocera, D. G. *J. Am. Chem. Soc.* **2006**, *128*, 13320–13321.
40. Isgor, Y. G.; Akkaya, E. U. *Tetrahedron Lett.* **1997**, *38*, 7417–7420.
41. Block, M. A. B.; Hecht, S. *Macromolecules* **2004**, *37*, 4761–4769.
42. Fu, N.; Baumes, J. M.; Arunkumar, E.; Noll, B. C.; Smith, B. D. *J. Org. Chem.* **2009**, *74*, 6462–6468.
43. Arunkumar, E.; Forbes, C. C.; Noll, B. C.; Smith, B. D. *J. Am. Chem. Soc.* **2005**, *127*, 3288–3289.
44. Law, K. Y.; Bailey, F. C.; Bluett, L. J. *Can. J. Chem.* **1986**, *64*, 1607–1619.
45. Oguz, U.; Akkaya, E. U. *J. Org. Chem.* **1998**, *63*, 6059–6060.
46. Beverina, L.; Salice, P. *Eur. J. Org. Chem.* **2010**, 1207–1225.
47. McEwen, J. J.; Wallace, K. J. *Chem. Commun.* **2009**, 6339–6351.
48. Ajayaghosh, A. *Acc. Chem. Res.* **2005**, *38*, 449–459.
49. Sreejith, S.; Carol, P.; Chithra, P.; Ajayaghosh, A. *J. Mater. Chem.* **2008**, *18*, 264–274.
50. Basheer, M. C.; Alex, S.; George Thomas, K.; Suresh, C. H.; Das, S. *Tetrahedron* **2006**, *62*, 605–610.
51. Arunkumar, E.; Ajayaghosh, A.; Daub, J. *J. Am. Chem. Soc.* **2005**, *127*, 3156–3164.
52. Oguz, U.; Akkaya, E. U. *Tetrahedron Lett.* **1998**, *39*, 5857–5860.
53. Akkaya, E. U.; Turkyilmaz, S. *Tetrahedron Lett.* **1997**, *38*, 4513–4516.
54. Ros-Lis, J. V.; Garcia, B.; Jimenez, D.; Martinez-Manez, R.; Sancenon, F.; Soto, J.; Gonzalvo, F.; Valldecabres, M. C. *J. Am. Chem. Soc.* **2004**, *126*, 4064–4065.
55. Umezawa, K.; Citterio, D.; Suzuki, K. *Anal. Sci.* **2008**, *24*, 213–217.
56. Gassensmith, J. J.; Arunkumar, E.; Barr, L.; Baumes, J. M.; DiVittorio, K. M.; Johnson, J. R.; Noll, B. C.; Smith, B. D. *J. Am. Chem. Soc.* **2007**, *129*, 15054–15059.
57. Cox, J. R.; Muller, P.; Swager, T. M. *J. Am. Chem. Soc.* **2011**, *133*, 12910–12913.

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

58. Warnan, J.; Buchet, F.; Pellegrin, Y.; Blart, E.; Odobel, F. *Org. Lett.* **2011**, *13*, 3944–3947.
59. Yu, H.; Fu, M.; Xiao, Y. *Phys. Chem. Chem. Phys.* **2010**, *12*, 7386–7391.
60. Levine, M.; Song, I.; Andrew, T. L.; Kooi, S. E.; Swager, T. M. *J. Polym. Sci., Part A: Polym. Chem.* **2010**, *48*, 3382–3391.
61. Levine, M.; Marks, P. Synthesis of a Near-Infrared Emitting Squaraine Dye in an Undergraduate Organic Laboratory. *J. Chem. Educ.* **2012**, submitted.
62. Wang, W.; Fu, A.; You, J.; Gao, G.; Lan, J.; Chen, L. *Tetrahedron* **2010**, *66*, 3695–3701.
63. Xiao, S.; Fu, N.; Peckham, K.; Smith, B. D. *Org. Lett.* **2010**, *12*, 140–143.
64. Law, K. Y.; Bailey, F. C. *J. Org. Chem.* **1992**, *57*, 3278–3286.
65. Chen, C.; Wang, R.-Y.; Guo, L.-Q.; Fu, N.-Y.; Dong, H.-J.; Yuan, Y.-F. *Org. Lett.* **2011**, *13*, 1162–1165.
66. Gupta, M.; Paul, S.; Gupta, R. *Curr. Sci.* **2010**, *99*, 1341–1360.
67. Aktoudianakis, E.; Chan, E.; Edward, A. R.; Jarosz, I.; Lee, V.; Mui, L.; Thatipamala, S. S.; Dicks, A. P. *J. Chem. Educ.* **2008**, *85*, 555–557.
68. Hooper, M. M.; DeBoef, B. *J. Chem. Educ.* **2009**, *86*, 1077–1079.
69. Pirrung, M. C.; Das Sarma, K. *J. Am. Chem. Soc.* **2004**, *126*, 444–445.
70. Pirrung, M. C.; Das Sarma, K. *Tetrahedron* **2005**, *61*, 11456–11472.
71. Chanda, A.; Fokin, V. V. *Chem. Rev.* **2009**, *109*, 725–748.
72. Breslow, R. *J. Phys. Org. Chem.* **2006**, *19*, 813–822.
73. Breslow, R. *Acc. Chem. Res.* **2004**, *37*, 471–478.
74. Breslow, R.; Groves, K.; Mayer, M. U. *J. Am. Chem. Soc.* **2002**, *124*, 3622–3635.
75. Narayan, S.; Fokin, V. V.; Sharpless, K. B. *Org. React. Water* **2007**, 350–365.
76. Acevedo, O.; Jorgensen, W. L. *J. Chem. Theory Comput.* **2007**, *3*, 1412–1419.
77. Singh, C. B.; Kavala, V.; Samal, A. K.; Patel, B. K. *Eur. J. Org. Chem.* **2007**, 1369–1377.
78. Naik, S.; Bhattacharjya, G.; Talukdar, B.; Patel, B. K. *Eur. J. Org. Chem.* **2004**, 1254–1260.
79. Kazmaier, P. M.; Hamer, G. K.; Burt, R. A. *Can. J. Chem.* **1990**, *68*, 530–536.
80. Meyers, F.; Chen, C.-T.; Marder, S. R.; Bredas, J.-L. *Chem. Eur. J.* **1997**, *3*, 530–537.
81. Lee, V. Y.; Sekiguchi, A. *Angew. Chem., Int. Ed.* **2007**, *46*, 6596–6620.
82. Breslow, R.; Groves, J. T. *J. Am. Chem. Soc.* **1970**, *92*, 984–987.
83. Arun, K. T.; Epe, B.; Ramaiah, D. *J. Phys. Chem. B* **2002**, *106*, 11622–11627.
84. Li, X.-H.; Zhang, B.-W.; Cao, Y. *Dyes Pigments* **2000**, *45*, 209–217.
85. Giusti, L. A.; Marini, V. G.; Machado, V. G. *J. Mol. Liq.* **2009**, *150*, 9–15.
86. Dsouza, R. N.; Pischel, U.; Nau, W. M. *Chem. Rev.* **2011**, *111*, 7941–7980.
87. El Seoud, O. A.; Loffredo, C.; Galgano, P. D.; Sato, B. M.; Reichardt, C. *J. Chem. Educ.* **2011**, *88*, 1293–1297.
88. Reichardt, C. *Pure Appl. Chem.* **2008**, *80*, 1415–1432.
89. Murugan, N. A.; Kongsted, J.; Rinkevicius, Z.; Aagren, H. *Phys. Chem. Chem. Phys.* **2011**, *13*, 1290–1292.
90. Machado, C.; Machado, V. G. *J. Chem. Educ.* **2001**, *78*, 649–651.

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

91. Berry, D. E.; Hicks, R. G.; Gilroy, J. B. *J. Chem. Educ.* **2009**, *86*, 76–79.
92. Green, W. P.; Trotochaud, A.; Sherman, J.; Kazerounian, K.; Faraclas, E. W. *J. Chem. Educ.* **2009**, *86*, 340–342.
93. Stella, L. *J. Chem. Educ.* **2011**, *88*, 695–696.
94. Jenkins, J. L.; Welch, L. E. *J. Chem. Educ.* **2009**, *86*, 613–616.
95. Chakraborty, M.; Chowdhury, D.; Chattopadhyay, A. *J. Chem. Educ.* **2003**, *80*, 806–809.
96. Weizman, H.; Nielsen, C.; Weizman, O. S.; Nemat-Nasser, S. *J. Chem. Educ.* **2011**, *88*, 1137–1140.
97. Schmidt, D. J.; Pridgen, E. M.; Hammond, P. T.; Love, J. C. *J. Chem. Educ.* **2010**, *87*, 208–211.
98. Burgess, I. B.; Rochon, P.; Cunningham, N. *Opt. Mater.* **2008**, *30*, 1478–1483.
99. Wang, S.; Hall, L.; Diev, V. V.; Haiges, R.; Wei, G.; Xiao, X.; Djurovich, P. I.; Forrest, S. R.; Thompson, M. E. *Chem. Mater.* **2011**, *23*, 4789–4798.
100. Qaddoura, M. A.; Belfield, K. D.; Tongwa, P.; DeSanto, J. E.; Timofeeva, T. V.; Heiney, P. A. *Supramol. Chem.* **2011**, *23*, 731–742.
101. Thomas, S. W., III; Joly, G. D.; Swager, T. M. *Chem. Rev.* **2007**, *107*, 1339–1386.
102. Andrew, T. L.; Swager, T. M. *J. Polym. Sci., Part B: Polym. Phys.* **2011**, *49*, 476–498.
103. Zhou, Q.; Swager, T. M. *J. Am. Chem. Soc.* **1995**, *117*, 12593–12602.
104. Liu, B.; Bazan, G. C. *Macromol. Rapid Commun.* **2007**, *28*, 1804–1808.
105. Traina, C. A.; Bakus, R. C., II; Bazan, G. C. *J. Am. Chem. Soc.* **2011**, *133*, 12600–12607.
106. Kim, J.; McQuade, D. T.; Rose, A.; Zhu, Z.; Swager, T. M. *J. Am. Chem. Soc.* **2001**, *123*, 11488–11489.
107. Zhao, D.; Swager, T. M. *Macromolecules* **2005**, *38*, 9377–9384.
108. Wu, C.; Peng, H.; Jiang, Y.; McNeill, J. *J. Phys. Chem. B* **2006**, *110*, 14148–14154.
109. Tian, Z.; Yu, J.; Wu, C.; Szymanski, C.; McNeill, J. *Nanoscale* **2010**, *2*, 1999–2011.
110. Levine, M.; Cordovilla, C.; Swager, T. M. *Polym. Prepr.* **2010**, *51*, 336.
111. Kuntzleman, T. S.; Kenney, J. B.; Hasbrouck, S.; Collins, M. J.; Amend, J. R. *J. Chem. Educ.* **2011**, *88*, 1565–1568.
112. Wu, C.; Zheng, Y.; Szymanski, C.; McNeill, J. *J. Phys. Chem. C* **2008**, *112*, 1772–1781.
113. Shi, J.; Votruba, A. R.; Farokhzad, O. C.; Langer, R. *Nano Lett.* **2010**, *10*, 3223–3230.
114. Tassa, C.; Shaw, S. Y.; Weissleder, R. *Acc. Chem. Res.* **2011**, *44*, 842–852.
115. Dennler, G.; Scharber, M. C.; Brabec, C. J. *Adv. Mater.* **2009**, *21*, 1323–1338.
116. Furlan, P. Y. *J. Chem. Educ.* **2009**, *86*, 705–711.
117. Blonder, R.; Joselevich, E.; Cohen, S. R. *J. Chem. Educ.* **2010**, *87*, 1290–1293.
118. Ponnu, A.; Anslyn, E. V. *Supramol. Chem.* **2010**, *22*, 65–71.

119. Levine, M.; Mako, T. Highly Efficient Energy Transfer for the Detection of Polycyclic Aromatic Hydrocarbons. *Supramol. Chem.* **2012**, submitted.
120. Hamai, S.; Sasaki, Y.; Hori, T.; Takahashi, A. *J. Inclusion Phenom. Macrocyclic Chem.* **2006**, *54*, 67–76.
121. Hamai, S. *J. Inclusion Phenom. Macrocyclic Chem.* **2010**, *67*, 471–481.
122. Pappenfus, T. M.; Hermanson, D. L.; Kohl, S. G.; Melby, J. H.; Thoma, L. M.; Carpenter, N. E.; da Silva Filho, D. A.; Bredas, J.-L. *J. Chem. Educ.* **2010**, *87*, 522–525.
123. Tillman, E. S.; Roof, A. C.; Palmer, S. M.; Zarko, B. A.; Goodman, C. C.; Roland, A. M. *J. Chem. Educ.* **2006**, *83*, 1215–1217.
124. Cortes, M. T.; Moreno, J. C. *J. Chem. Educ.* **2005**, *82*, 1372–1373.
125. Duval-Terrie, C.; Lebrun, L. *J. Chem. Educ.* **2006**, *83*, 443–446.
126. Fleissner, A.; Stegmaier, K.; Melzer, C.; von Seggern, H.; Schwalm, T.; Rehahn, M. *Chem. Mater.* **2009**, *21*, 4288–4298.
127. Parekh, B. P.; Tangonan, A. A.; Newaz, S. S.; Sanduja, S. K.; Ashraf, A. Q.; Krishnamoorti, R.; Lee, T. R. *Macromolecules* **2004**, *37*, 8883–8887.
128. Jin, Y.; Kim, J. Y.; Song, S.; Xia, Y.; Kim, J.; Woo, H. Y.; Lee, K.; Suh, H. *Polymer* **2008**, *49*, 467–473.
129. Swager, T. M. *Acc. Chem. Res.* **2008**, *41*, 1181–1189.

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch003

Chapter 4

Introducing Scientific Writing in a Second Semester Organic Chemistry Laboratory Course

Allison A. Schmitt[1] and James A. Parise[2,*]

[1]Department of Chemistry, B120 LSRC, Duke University, Durham, NC 27708
[2]Department of Chemistry and Biochemistry, University of Notre Dame, Notre Dame, IN 46556
[*]Corresponding Author email: james.parise@nd.edu

We implemented a laboratory program that integrates an introduction to scientific reading and writing with standard wet experiments common to a second-semester organic chemistry course. The revisions described were part of an overhaul of the two-semester organic laboratory program that included development of virtual lab exercises, or 'dry labs', to compliment traditional wet experiments. The dry lab exercises in the second-semester program focused on the progressive development of scientific writing skills, as well as a continuing reinforcement of important chemistry concepts presented in wet labs. Through a virtual interface, students were instructed on the proper methods to write individual sections of a scientific paper. At the end of the semester, students wrote a full scientific paper to demonstrate the concepts and writing techniques learned throughout the semester. Students reported significant gains in scientific writing skills, and we reduced required staffing and laboratory space. We report here on our initial experiences using this laboratory program, starting in the Fall semester of 2010.

In Advances in Teaching Organic Chemistry; Duffy-Matzner, J., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2012.

Introduction

Background

The development of scientific literacy and technical writing skills is crucial for undergraduate students regardless of discipline (*1–3*). Students pursuing careers in medicine, law, engineering, science, and other disciplines benefit from development in these areas (*4*). Indeed, "writing across the curriculum" initiatives have arisen at many universities (*5*, *6*). Despite educators' appreciation for the importance of this skill set, reading and writing in the sciences tends to be deemphasized at the introductory levels in favor of theory and test taking activities in the lecture hall, and data gathering and technique introductions in the laboratory.

At many colleges and universities, students typically enroll in large introductory general and organic chemistry lectures containing hundreds of students. This large lecture format is generally not conducive to writing instruction due to the logistics inherent in grading hundreds of writing assignments at a time. Students may not receive direct writing instruction through introductory chemistry courses or other writing courses (*7*), leaving students underprepared for upper-level writing projects.

Most traditional laboratory programs accompanying these large introductory lecture sections require students to complete a sequence of experiments and then write a laboratory report summarizing the observations or results obtained for each experiment. The guidelines for writing these reports can be loosely defined and may range from simply submitting notebook pages and a typed discussion section to the writing of a full formal report containing an abstract, an experimental section, a results and discussion, and so on (*8*). However, students at this level have typically received little formal training in proper scientific writing format and techniques (*7*). Writing samples from untrained students may read like book reviews, literary commentaries, or cooking recipes due to this lack of training. Despite the absence of formal training, students are generally expected to be scientifically literate in advanced laboratory courses and during independent research experiences (*2*, *3*). This situation led us to consider methods of strengthening our curriculum in the areas of scientific reading and writing.

Duke University has recently endeavored to foster writing across various disciplines by requiring students to take several writing courses during their undergraduate careers (*9*). In addition, the Chemistry Department was particularly interested in improving student writing skills for several reasons. Although previously the general and organic chemistry laboratories had not required significant technical writing, the physical and analytical chemistry laboratories taken by chemistry majors require significant writing in the form of extensive laboratory reports. Instructors teaching the more advanced laboratory courses often reported inconsistent or unacceptable writing samples from students. In addition, a large number of chemistry majors (and majors in other scientific disciplines) write senior honors theses to fulfill requirements for graduation with honors. The principal investigators or graduate students supervising the work oftentimes spent great effort on correcting basic writing errors rather than evaluating the scientific merit of the work.

We surmised that we could improve our overall laboratory sequence by providing a broad overview of the basics of scientific reading and writing earlier in the undergraduate curriculum. Although comprehensive writing instruction at the introductory level is impractical (for reasons noted above), a general introduction to the formalities and best practices is reasonable. Students and instructors would benefit from increased student familiarity with scientific literacy and writing. In particular, with a stronger fundamental background in these areas, students could spend more time on the development of research projects and initiatives (*10*).

We felt that writing instruction was most appropriately introduced in the laboratory setting of a second semester organic chemistry course for several reasons. Although the laboratory course has the same total number of students as the lecture course, laboratory sections generally have far fewer students and thus better student-to-instructor ratios. The small section setting (at Duke, 14 students each) would allow for individual attention to writing development for students and grading would be a manageable task for teaching assistants. In addition, students at this level should have an adequate scientific background, making the development of the key skills of scientific interrogation and critical thinking in the context of laboratory activities reasonable.

The importance of scientific communication has been highlighted in the context of introductory laboratory development (*9*, *11*) and many educational institutions have used the laboratory setting to foster improved writing skills. As early as high school, students have benefitted from writing initiatives in the laboratory, although the effectiveness of these programs has varied because many students have not yet sufficiently developed scientific reasoning skills (*12*, *13*). A number of writing initiatives for more advanced groups of undergraduate laboratory students (*14–18*) and efforts to provide writing instruction in nonmajors courses (*19*) have been documented.

However, fewer examples exist for the development of writing skills in a collegiate introductory level course intended for majors. The existing examples highlight the scientific method, scientific literature, and the components of a scientific paper in the context of laboratory exercises (*20*, *21*). Pedagogical developments, including the science writing heuristic, have also been explored as they relate to the construction of writing skills, although writing skills in this context tend to be promoted in the framework of science inquiry (*22*). Using the context of the sections of a scientific paper, sequential development of writing skills was shown to aid in improving students' critical thinking skills and understanding of scientific method and practices (*23*).

Parameters for the Program Revision

All revisions needed to be designed with consideration of the parameters already in place at Duke University. Primarily, these factors included the order of course offerings, the relationship of the lab to the lecture portion of the course, and the time allotted for in-class laboratory meetings. Additionally, we considered the demographics of the student population and teaching assistants.

Introductory chemistry classes at Duke are taught in a '1-2-1' sequence. The majority of matriculating students take one semester of general chemistry followed by the first semester of organic chemistry (Organic 1) in the spring. During their second year, students enroll in a second semester of organic (Organic 2) in the fall, and then a second semester of general chemistry in the spring. Each introductory course is accompanied by a laboratory course to be taken concurrently with the lecture. The organic labs are worth 25 % of a student's grade in organic chemistry. A subset of students with Advanced Placement credit start with Organic 1 in the fall of their first year, and Organic 2 in the following spring.

The demographic information for Organic 2 courses taught in Fall 2010 and Spring 2011 is shown in Table I. The majority of students (n=462) were sophomores and pre-majors. Although there is no "pre-med" major at Duke, the majority of students enrolled in Organic 2 intend to pursue professional health degrees (medical, dental, or veterinary). Historically, an average of 20 % of these students eventually declare as chemistry majors (on average, 54 students per year).

Table I. Student Demographics in Fall 2010 and Spring 2011.

	Fall 2010	*Spring 2011*	*Total*	*Percentage*
Class	*(n = 238)*	*(n = 224)*	*(n = 462)*	
Freshman	0	105	105	22.7
Sophomore	205	94	299	64.7
Junior	26	18	44	9.5
Senior	7	6	13	2.8
Other	0	1	1	0.2
Majors				
Biological Sciences	13	15	28	6.1
Engineering	36	56	92	19.9
Humanities	6	4	10	2.2
Other	0	1	1	0.2
Physical Sciences	1	1	2	0.4
Social Sciences	10	10	20	4.4
Undeclared	172	137	309	66.9

Prior to the program revisions described in this chapter, students attended 11 weekly lab section meetings during the term. Lab periods were three hours long and individual laboratory sections contained up to 14 students each. No effort was made to separate students by grades, lecture section or grade level. The labs were administered by a graduate or advanced undergraduate student teaching assistant. The lab TAs were trained by the laboratory manager and were responsible for administering a pre-lab lecture and quiz, overseeing students as they conducted experiments, and grading lab reports and pre-lab quizzes.

We considered the inherent difficulties of providing consistent educational experiences with a large number of teaching assistants. Inconsistencies in teaching assistant chemical knowledge, writing skills and mastery of English language could greatly affect the quality and consistency of instruction given. Also, ensuring fairness of grading and feedback could be difficult given the different levels of TA experience and writing proficiency. In addition, adding a writing component could greatly increase the workload for teaching assistants, as time and labor are required to read and give constructive feedback on assignments.

Any revisions to the program were thus subject to the following logistical parameters: the three hour weekly lab period, the diversity and size of the TA pool, and the large number of students who would be distributed across many small lab sections.

Goals of the Lab Program Revision

Working within the logistical constraints outlined in the previous section, we aimed to develop a lab curriculum that accomplished three primary goals. First, we sought to preserve the experiments that were most effective at demonstrating reactions and principles emphasized in the lecture program. We also chose to eliminate some experiments that were redundant, expensive to operate, or less relevant to the material taught in lectures. Second, we wanted to provide students with a broad introductory exposure to scientific reading and writing. To accomplish this goal, we needed to develop a method to expose students to proper scientific writing, and then we would provide a series of training exercises and opportunities to practice these skills. Third, we wanted to lower the overall cost of running the labs by reducing the total number of TAs and TA hours necessary for operation of the program. In recent years, the department would often need to hire outside of the graduate student pool in order to provide enough TAs to staff every lab section. Under the new format, each teaching assistant could teach twice as many lab sections (and thus teach up to twice as many students) in a given semester. However, our goal was to not increase TA contact hours, and in many cases we were able to decrease the average number of student contact hours for TAs. TAs could then spend more time analyzing and evaluating student lab reports.

To accomplish these goals, we made three major changes within the lab program. We designed a meeting schedule where students would attend lab and conduct an experiment every other week, and complete virtual assignments (called “dry labs”) in the intervening weeks. Additionally, we developed new reading and writing-focused exercises designed to be administered as dry labs. Finally, we employed an online learning system capable of hosting materials, administering graded assignments, and providing feedback to students. The development of these materials and our experiences with their implementation is described in the next section.

Lab Program Design and Implementation

We accomplished each of the goals outlined in the previous section by reworking the structure of the laboratory course, developing new materials, and utilizing technology to administer materials.

Structure of Course

Instead of a weekly laboratory meeting schedule, students in the revised program met in the laboratory every other week to conduct an experiment. During the "off" weeks, students would perform a virtual experiment, or "dry lab". Students were split into two equal-sized cohorts, based on whether they were in an odd-numbered or even-numbered lab section (section numbers were randomly assigned by the University). The first group met with their TAs in lab during the first week of the term to complete their first experiment. The second group had no assignment during the first week. During the second week of lab, the first group independently completed the first dry lab assignment, while the second group met in lab to conduct the first experiment. During the third week, the first group returned to the lab to conduct the second experiment with the TA, while the second group completed the dry lab assignment independently. This staggered attendance model (Figure 1) allowed TAs to supervise up to twice the number of students. TAs could teach twice as many sections since they only attended wet lab exercises, while maintaining the same number of total contact hours. The students completed a total of six wet labs under the supervision of their TA and five dry labs independently, alternating over eleven weeks.

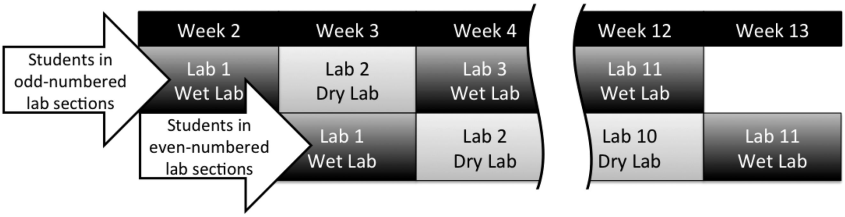


Figure 1. Graphical representation of alternating wet/dry lab schedule.

The wet labs consisted of traditional experiments based on standard lab textbook procedures or experiments developed in-house. The dry lab activities included two components: completion of exercises related to the previous week's experiment (described below), and composition of one section of a scientific paper. The schedule of activities is shown in Table II.

Table II. Schedule of lab activities.

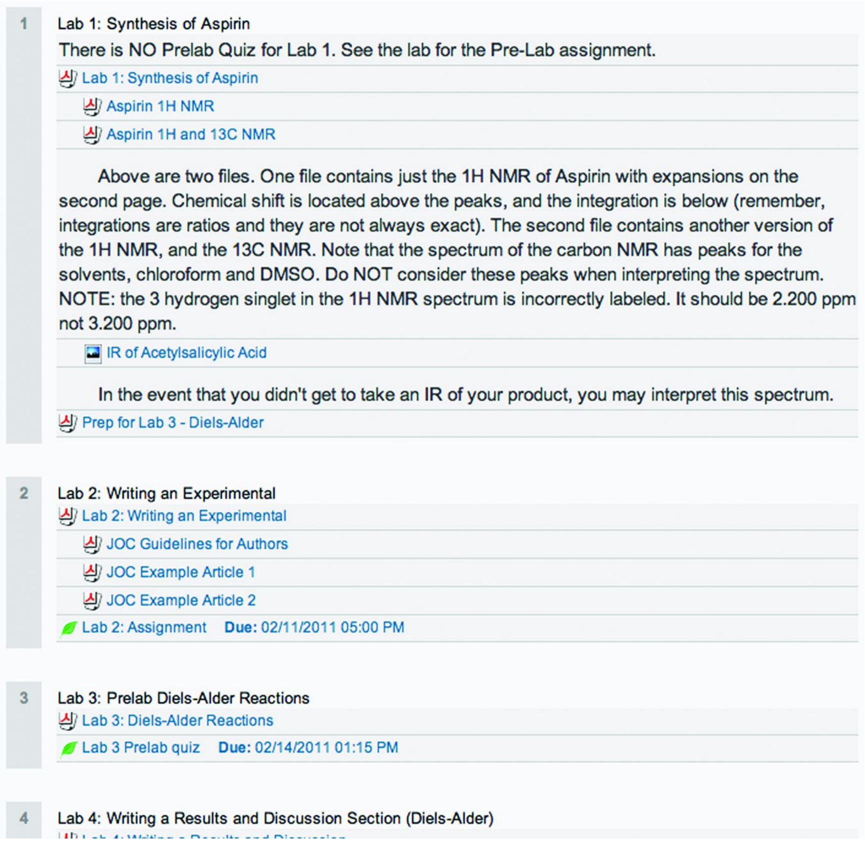
Week	*ODD-NUMBERED LAB SECTIONS*	*EVEN-NUMBERED LAB SECTIONS*
1	• Pre-lab 1 notebook/reading	
2	• Lab 1. Synthesis of Aspirin	No Lab for Even Sections
3	• Lab 2. Writing an Experimental • Pre-lab Quiz 3	• Lab 1. Synthesis of Aspirin
4	• Lab 3. Diels-Alder Reactions	• Lab 2. Writing an Experimental • Pre-lab Quiz 3
5	• Lab 4. Writing Results & Discussion • Pre-lab Quiz 5	• Lab 3. Diels-Alder Reactions
6	• Lab 5. Electrophilic Aromatic Substitution	• Lab 4. Writing Results & Discussion • Pre-lab Quiz 5
7	• Lab 6. Writing an Abstract • Pre-lab Quiz 7	• Lab 5. Electrophilic Aromatic Substitution
8	• Lab 7. Grignard Reaction – Synthesis of Triphenylmethanol	• Lab 6. Writing an Abstract • Pre-lab Quiz 7
9	• Lab 8. Writing an Introduction • Pre-lab Quiz 9	• Lab 7. Grignard Reaction – Synthesis of Triphenylmethanol
10	• Lab 9. Organic Chemistry and Drug Development	• Lab 8. Writing an Introduction • Pre-lab Quiz 9
11	• Lab 10. Writing a Scientific Paper • Pre-lab Quiz 11	• Lab 9. Organic Chemistry and Drug Development
12	• Lab 11. Recycling PET	• Lab 10. Writing a Scientific Paper • Pre-lab Quiz 11
13	No Lab for Odd Sections	• Lab 11. Recycling PET

Note: Lightly shaded items were completed independently by students outside of lab.

Distribution of Electronic Materials and Dry Labs

As in the Organic 1 lab course we developed at Duke (results unpublished), we used Sapling Learning (www.saplinglearning.com) as a web-based platform for administering assignments and course materials. Pre-lab assignments and quizzes, wet lab procedures, and dry lab materials (including readings, links and sections of scientific papers) were administered through Sapling's online platform. Previous studies have indicated that administrative tasks can be reduced substantially through the utilization of an online platform for course delivery (*24*). In addition, online writing instruction has been shown to provide learning benefits for students (*25*).

Sapling was selected for a number of reasons. First, the interface was used as a platform for posting electronic materials integrated with graded assignments like quizzes or dry lab exercises. We were able to group items, whether they were assignments or reading materials, into modules that were released each week (Figure 2). For student assignments, we were able to easily generate questions and activities that reinforced the topics of the labs. Sapling also had a large pool of pre-existing questions that we could access and integrate into our program. Students could access their Sapling assignments for the entire week at any time of the day.



1

Lab 1: Synthesis of Aspirin

There is NO Prelab Quiz for Lab 1. See the lab for the Pre-Lab assignment.

Lab 1: Synthesis of Aspirin

Aspirin 1H NMR

Aspirin 1H and 13C NMR

Above are two files. One file contains just the 1H NMR of Aspirin with expansions on the second page. Chemical shift is located above the peaks, and the integration is below (remember, integrations are ratios and they are not always exact). The second file contains another version of the 1H NMR, and the 13C NMR. Note that the spectrum of the carbon NMR has peaks for the solvents, chloroform and DMSO. Do NOT consider these peaks when interpreting the spectrum. NOTE: the 3 hydrogen singlet in the 1H NMR spectrum is incorrectly labeled. It should be 2.200 ppm not 3.200 ppm.

IR of Acetylsalicylic Acid

In the event that you didn't get to take an IR of your product, you may interpret this spectrum.

Prep for Lab 3 - Diels-Alder

2

Lab 2: Writing an Experimental

Lab 2: Writing an Experimental

JOC Guidelines for Authors

JOC Example Article 1

JOC Example Article 2

Lab 2: Assignment **Due:** 02/11/2011 05:00 PM

3

Lab 3: Prelab Diels-Alder Reactions

Lab 3: Diels-Alder Reactions

Lab 3 Prelab quiz **Due:** 02/14/2011 01:15 PM

4

Lab 4: Writing a Results and Discussion Section (Diels-Alder)

Figure 2. Screen capture of Sapling Learning's material distribution interface. Shown is a portion of the Spring 2011 syllabus for Organic 2.

Lab Program Content

In general, the foci of the wet lab activities were to provide students with experience running a set of reactions and to reinforce key reactions studied throughout the semester. Among the topics included in the program were carbonyl chemistry including hydrolysis of esters and hydrazone formation, the

Grignard reaction, electrophilic aromatic substitution (EAS), and Diels-Alder reactions. The lab methods and techniques used in experiments included reflux, diastereomeric resolution, moisture sensitive reactions, combinatorial library synthesis, microbiology, and green chemistry. We eliminated two multi-week experiments from our previous program: a qualitative analysis lab and a multi-step synthesis of the sweetener dulcin. The costly nature and wastefulness of organic qualitative analysis in contemporary lab programs has been noted (*26*). While we appreciated the pedagogical benefits of this activity, we decided to eliminate the experiment because many the methods are no longer used in the modern lab. Additionally, the excess costs of reagents for "unknowns" and the generation of toxic 2,4-DNP derivatives were significant drawbacks. The dulcin synthesis lab was eliminated because of its redundancy with the "Synthesis of Aspirin" lab (Lab 1). The procedure included an hour-long reflux and the chemistry focused on carbonyl addition reactions. Both of these themes were already emphasized in a number of our other labs.

During the weeks between the scheduled wet labs, a total of five dry labs were completed by students independently. All instructions and graded assignments were administered online through Sapling. Our two primary objectives for these exercises were to reinforce the concepts learned in the wet laboratory and provide students with the opportunity to become more literate and proficient in scientific writing.

Each dry lab assignment consisted of three parts. The first part was a document detailing the relevant aspects and appropriate features of each section of a scientific paper. Students were also provided with references to examples of quality scientific writing from the literature for each section. The next part was a graded assignment on Sapling containing questions related to the document and topics from the previous week's wet lab. Finally, students were given a writing assignment based on the previous week's experiment to be submitted to their TA the next week.

Lab Assignments

In the first wet lab (Lab 1), students conducted a standard synthesis of aspirin from salicylic acid. In the first dry lab activity (Lab 2), students were introduced to scientific writing and guidelines for authors from the *Journal of Organic Chemistry*. Through Sapling, students were provided with two sample articles for perusal, and they also reviewed a document outlining the key features of writing an experimental section of a scientific paper. They then completed an online assignment administered and graded through Sapling. The assignment contained post-lab questions related to concepts from the first wet laboratory activity (Synthesis of Aspirin) and several questions designed to assess understanding of appropriate information and writing style for the experimental section of a scientific paper. Finally, students were assigned to write an experimental section on the synthesis of aspirin for submission with the Lab 1 report.

After completing the second wet lab (Lab 3), the second dry lab (Lab 4) provided background on the components of a results and discussion section of a paper, including schemes, figures, and tables. In general, students were most familiar with the results and discussion section as they had been expected to write several short "discussion" sections on the laboratory experiments conducted in General Chemistry and Organic Chemistry 1. The online assignment consisted of questions related to Diels-Alder reactions (including stereospecificity) and questions related to results and discussion sections. Students were then provided with several questions intended to serve as discussion points for the Diels-Alder assignment.

Electrophilic aromatic substitution (EAS) reactions were introduced in Lab 5. In the following dry lab (Lab 6), students were provided background on the composition of an abstract and were directed to several examples of abstracts in the literature. The online assignment consisted of questions reinforcing the chemical concepts from the EAS wet lab. Students were also asked to complete questions testing their knowledge of appropriate content for the experimental, results and discussion and abstract sections of a scientific paper. An abstract and a results and discussion section based on the EAS lab were assigned as the writing components for this lab.

Lab 7 focused on Grignard reactions. For the dry lab assignment (Lab 8), students were provided with a description of the objectives of the introduction of a scientific paper and referred to appropriate articles. The online Sapling assignment consisted of a series of questions related to Grignard reactions. Students were also assigned exercises in which they would determine where specific sample sentences would fit into sections of a paper (i.e. in the abstract, results, etc.). All sections of a scientific paper were addressed in these questions. The writing component for this dry lab was an introduction to their Grignard lab report as well as the standard results and discussion section.

The penultimate wet lab of the term (Lab 9) was an experiment bridging combinatorial chemistry and microbiology, based on a published experiment (*27*). For the final dry lab (Lab 10), students wrote a full scientific paper based on Lab 9. A four page limit on papers was given, providing the students with the opportunity to address all of the sections of a scientific paper with a word limit encouraging brevity and good technical writing skills. The online assignment consisted of reinforcement activities on the wet lab and writing exercises reviewing proper topics and styles for all sections of a scientific paper. The last wet lab (Lab 11) had no associated writing assignment.

Online Pre-Lab Quizzes

We used the Sapling platform to administer a pre-lab quiz to students before each wet laboratory exercise. On average, pre-lab quizzes were completed in approximately thirty minutes. It was advantageous to administer the pre-lab quizzes electronically prior to the lab meeting. When quizzes were administered in lab, they had to be relatively short to allow enough time for completing experiments. By allowing students to complete quizzes online before the lab, we could more effectively utilize lab time for experiments, and the quizzes could thus be longer and more comprehensive. Additionally, TA time was utilized more efficiently as online assignments were graded automatically.

Previous literature has demonstrated that online pre-laboratory exercises promote student confidence and encourage student attention to detail in laboratory exercises (*28*). Our goals were to ensure student preparation and comprehension for the scheduled laboratory exercise. The quizzes tested knowledge of relevant background material and reading comprehension for the protocol and procedures of each experiment. In addition, the quizzes emphasized appropriate safety practices for the chemicals and techniques of each experiment.

Grading

As stated previously, one goal of the revisions to the lab program was to provide students with a general first exposure to the components of the different sections of a scientific paper. Due to large enrollments and varying degrees of TA experience, competency, and time, we did not aim to provide students with comprehensive writing critiques. Instead, TAs were provided with detailed grading rubrics for evaluation of the written reports, summarized in Table III. Students were evaluated primarily on whether or not each new section contained the proper components in the proper places.

Five lab reports were submitted to TAs over the semester. The first four lab reports were worth 20 points, with each successive report focused on a different section of a scientific paper as described previously. The final full written report (Lab 9) was a complete scientific paper containing all sections and was worth 24 points. Lab 11 was worth only 16 points as there was no formal writing required. The first lab report (Lab 1 and 2) contained a written experimental section conforming to *JOC* standards worth six out of the 20 points for the lab (30 % of total points). TAs were instructed to look for proper presentation of NMR and IR data, whether the section was consistently written in the past tense, and if quantities of reagents and products were reported in both grams and moles. For the second lab report (Lab 3 and 4), a results and discussion section worth ten out of 20 points (50 %) required students to report data including their percent yields and recovery, purity, and analysis spectroscopic data. They discussed the results of their experiment, and whether their results were consistent with their pre-experiment hypothesis. In the third lab report (Lab 5 and 6), an abstract was assigned worth four of 20 points (20 %). The abstract was critiqued for brevity and content. The fourth report (Lab 7 and 8) required an introduction worth five out of 20 points (25 %). Students were instructed to include a broad background on the Grignard reaction, general difficulties in carrying out such reactions, and mention of the specific reaction to be attempted in that experiment. Finally, the capstone full scientific paper (Lab 9 and 10) required students to report on the findings of their last experiment and submit a report containing all four sections. The assignment was worth 24 points, 17 points (71 %) of which were assigned for writing. In all labs, the remaining points not associated with the writing exercises were accounted for in pre-lab assignments, in-lab procedures, and a post-lab data summary worksheet.

Table III. Summary of Grading Rubrics.

Lab 1: Synthesis of Aspirin & Lab 2: Writing an Experimental	(20 pts)
Worksheet	8
Discussion Questions	6
Experimental	6
• Proper format	
• Past tense	
• Interpret IR/NMR data	
• Grams/moles reported for all reagents/products	
• General format and structure	
Lab 3: Diels-Alder & Lab 4: Writing a Results and Discussion	(20 pts)
Worksheet	10
Results and Discussion	10
• What was synthesized	
• Do results support hypothesis	
• Report % yield and % recovery	
• Purity: melting point, IR data	
• Discuss theory	
• Analysis	
Lab 5: EAS & Lab 6: Writing an Abstract	(20 pts)
Worksheet	8
Results and Discussion	8
Abstract	4
• 2-4 sentences	
• Contains relevant data	
• Contains no extraneous data	
Lab 7: Grignard Reaction & Lab 8: Writing an Introduction	(20 pts)
Worksheet	7
Results and Discussion	8
Introduction	5
• Broad background	
• General difficulties with Grignard reactions	
• Mention of specific reaction	
Lab 9: Drug Development & Lab 10: Writing a Research Paper	(24 pts)
Worksheet	7
Abstract	4
Introduction	4
Results and Discussion	6
Experimental	3
Lab 11: Recycling PET	(16 pts)
Dry Lab Sapling Exercises (5 total, 14 pts each)	(70 pts)

Continued on next page.

Table III. (Continued). Summary of Grading Rubrics.

Pre-lab quizzes (5 total, 6 pts each)	(30 pts)
General lab preparedness and other points	(30 pts)
TOTAL	**(250 pts)**

One of the advantages of the Sapling interface was that we could easily monitor grade averages across TAs as the semester progressed. Differences in average grades by section varied no more than 2% on either side of the overall course average. As such, no grade normalization operation was performed at the end of the semester.

Evaluation

We evaluated our course revisions in a number of ways. Students were asked to provide feedback through online surveys on a variety of questions, including their experiences with the online format and their perceptions of writing skill development through the semester. In addition, we assessed whether or not we had achieved the goals we had outlined prior to the course revision.

Results of Student Surveys

We attempted to ascertain student feedback regarding the Sapling platform and online assignments by administering a survey at the end of the term. A total of 363 students responded to these questions in either Fall 2010 or Spring 2011.

Student Feedback on Format and General Parameters

The results of our general survey questions are shown in Table IV. Almost two-thirds of students surveyed (63 %) said they had used some type of online chemistry software prior to the use of Sapling this semester. Of these students, 54% felt that the Sapling platform was preferable to the software they had previously used, while 12 % of students felt the Sapling platform was worse. A vast majority of students (91 %) said that Sapling software was easy to use or acceptable. Most students (81 %) felt that the questions asked through Sapling were of average difficulty. About half of the students (49 %) felt that they spent more time on assignments than was reflected by the number of points they earned. Finally, 77 % of students reported working independently on assignments, as we had intended.

Table IV. General Feedback about Sapling and Assignments.

	Yes	*No*	
Have you used online software in any other Chemistry course prior to this semester?	227 (63 %)	136 (37 %)	
	Better	*Same*	*Worse*
If you answered yes to the above question, how would you compare Sapling, in terms of overall performance?	123 (54 %)	87 (38 %)	27 (12 %)
	Easy	*Average*	*Difficult*
Generally, how difficult did you find the individual questions?	44 (12 %)	295 (81 %)	24 (6.6 %)
	Yes	*Sometimes*	*No*
Did you work together with others when completing assignments?	11 (3.0 %)	73 (20 %)	279 (78 %)
	Easy	*Neutral*	*Difficult*
How would you rank the ease of use and technical issues related to the software interface?	199 (55 %)	133 (37 %)	17 (4.7 %)

Student Feedback on Writing Development and Quality of Supplemental Materials

Students were also surveyed on a number of issues related to the revised course content and format. They were first asked for their perceptions on their writing abilities after a semester of writing instruction through the virtual laboratory assignments and additional writing assignments. Figure 3 shows this data in the category entitled "Were Learning Objectives Met?"

A majority (65 %) of students overall felt that their knowledge of scientific writing improved, while only 20 % of students felt that their knowledge did not improve in some way. Of the 37 students who left additional feedback about the writing components, several (eight, 2.2 % overall) commented that the exercises in which students were asked to place sentences in the appropriate section of the scientific paper were too difficult or confusing. Notably, all eight of these comments were made in the fall semester. We made revisions to these questions to clarify content and received no comments of this type in Spring 2011. Also, several students (14, 3.9 % overall) commented that they enjoyed the scientific writing exercises, while 12 students commented that they did not enjoy the exercises. Of those students, most mentioned that they would have preferred more wet labs instead of additional writing exercises.

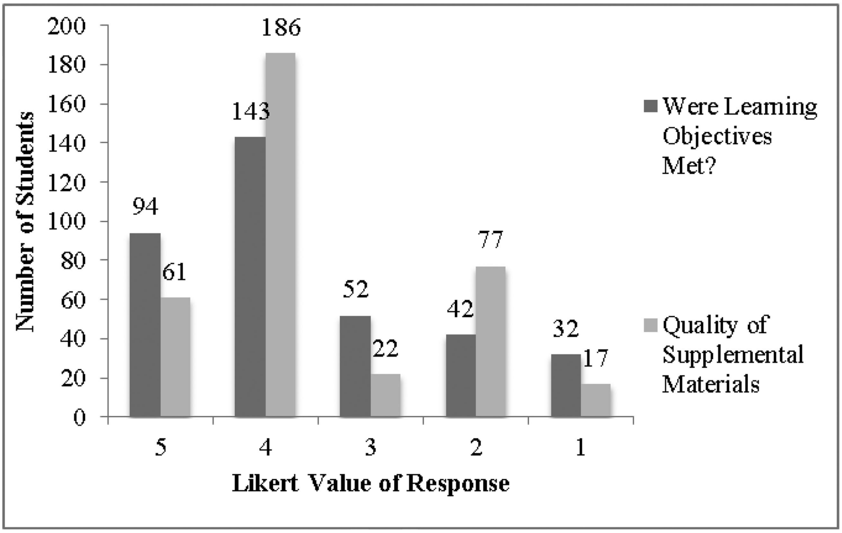


Figure 3. Results from Likert-Style Survey on Learning Objectives and Quality of Supplemental Materials. (Prompt for Learning Objectives Question was: The writing exercises in each dry lab were designed to introduce you to, one section at a time, the different parts of a scientific paper. The semester culminated with the writing of a complete paper. Do you agree that your knowledge of scientific writing increased and your writing skills improved over the term? Responses ranged from Agree - 5 to Disagree - 1. Prompt for Supplemental Materials question was: Do you feel that the supplemental materials provided (the sample JOC articles, sections from the Guidelines for Authors document) were useful in your preparations prior to writing your Post Labs? Responses ranged from Very Useful - 5 to Not at All Useful -1.)

Figure 3 also shows student perceptions of the quality of supplemental materials provided in the course, in the category “Quality of Supplemental Materials.” The majority of students (68 % of respondents) felt that the materials provided were either very useful or somewhat useful in developing scientific writing skills. Only four students commented directly that the materials were not helpful, and in general feedback on the sample articles was very positive.

Level of Scientific Reading and Writing Exposure

Students were also queried as to whether the level of exposure to scientific reading and writing was provided at an appropriate level given their background and previous experiences. The results of this survey question are shown in Figure 4. Encouragingly, 87 % of students felt that the exposure to scientific reading and writing was at an appropriate level given their previous experience. In terms of future applications of this curriculum, 63 % of students reported that they are already involved in research or plan to do research in the future.

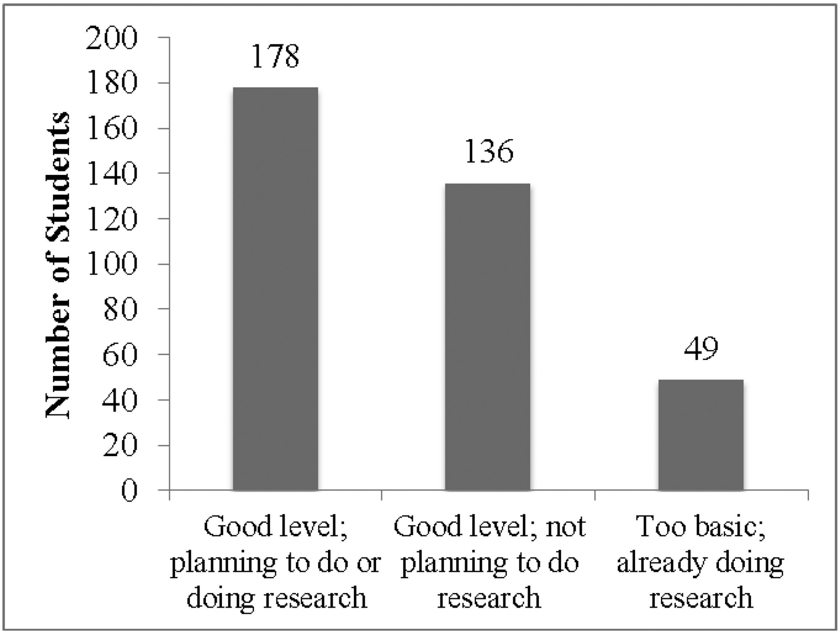


Figure 4. Appropriateness of Scientific Exposure to Reading and Writing Skills. Students were asked: How appropriate do you feel the exposure to scientific reading and writing was to you?

Preferences on Current Curriculum (Wet/Dry Lab) versus a Wet-Lab Based Curriculum

We then asked students about their preferences for an alternating wet/dry lab curriculum versus a predominantly wet lab based lab curriculum. The results of the feedback for this question are shown in Figure 5. Overall, 66 % of student respondents preferred the current curriculum of alternating wet and dry lab activities. Many students (123) left additional feedback on the survey on this issue. A number of students (32, 8.8 % overall) stated they would have preferred to have more wet labs or that the wet labs were better. However, 70 students (19 % overall) stated that they preferred the wet/dry lab format in the comments. Of these students, 30 (8.3 % overall) said that it was because they had more time to do other activities, and 16 students (4.4 % overall) specifically stated that they had a better learning experience with the new curriculum.

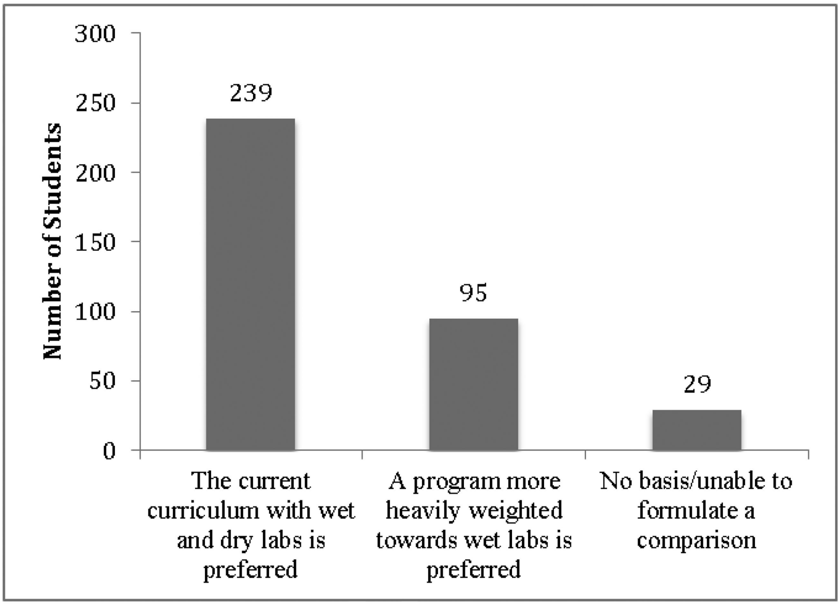


Figure 5. Student Preferences on Current Curriculum versus a predominantly Wet Lab Curriculum. Students were asked: How would you compare this curriculum, containing alternating wet and dry labs, to one containing mostly wet labs?

An overall reduction in workload or in-lab time was the main reason given by students who stated their preference for the revised program format. A significant minority stated they felt that the revised program provided a better learning experience. Those students who would have preferred a program with more wet labs offered thoughtful reasons, stating that although the dry labs were useful, they should not come at the expense of hands-on experiments.

Ratings of Dry Lab Writing Activities

We analyzed the survey data to determine student preferences for the virtual laboratory assignments from Organic 2 using a Likert-style survey. The results of this survey are shown in Figure 6. Students recommended that all labs be kept in the program. The results and discussion dry lab received the highest rating (3.80/5.00), possibly because students were most comfortable with this type of writing based upon prior lab experiences. Since students were expected to write results and discussion sections for most of the other lab exercises in the course (Labs 6, 8 and 10), the lessons learned during this dry lab may have had the most impact on their grades and experience in the course.

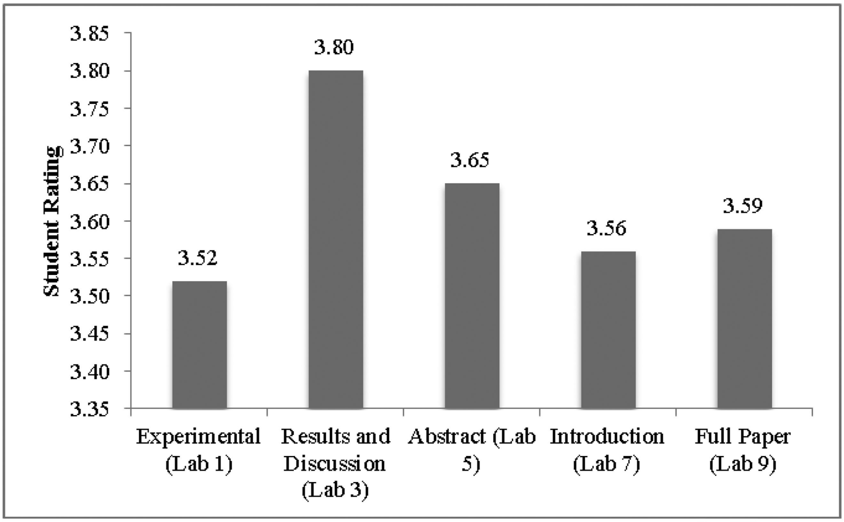


Figure 6. Student Ratings for Dry Lab, Writing-Focused Activities. Student prompt was: Do you recommend keeping the following lab in the Organic 2 lab curriculum? Activities were rated on a scale from 1 – 5 (definitely should not keep activity =1, definitely should keep activity = 5)

Overall Impressions of Revised Program

In general, we achieved each of our primary goals of the course revision. We preserved the wet lab exercises deemed most relevant and useful to the second semester organic student while eliminating some labs that were redundant or costly.

Our goal of providing a broad introduction to scientific reading and writing was also achieved. Some of the students who completed this program will enroll in advanced lab courses and write senior theses. Unfortunately, direct assessment of whether "students became better writers" as a result of the program is challenging for a number of reasons. Typically, ten or fewer students enroll in the upper level laboratory (physical, analytical) courses in the chemistry department each semester and instructors in those courses say that writing samples from term to term vary widely (personal communication). However, it would be unrealistic to fathom that students did not benefit from getting a pre-exposure to scientific writing. In addition, the crafting of a senior honors thesis is a very individual endeavor, and currently no metrics exist in the department to rate the writing quality of the senior theses submitted each year.

We were able to substantially reduce costs and time related to operating the program. The overall budget required for laboratory activities was reduced by about a quarter due to hiring only half the number of undergraduate TAs previously required to staff all lab sections. In addition, the operations budget was reduced by approximately 20 % over the course of the semester. In addition, fewer graduate teaching assistants were required to serve the same number of students:

TAs presided over five sections every two weeks, down from six sections every two weeks in the old program. TAs were thus able to use extra teaching time to provide more thorough feedback and read more substantial laboratory reports. The use of Sapling's online platform for distribution and grading of quizzes and assignments also saved time and resources.

Certainly, there are legitimate factors to consider when contemplating decreasing the amount of in-lab experience students receive, such as we have done in our course revision. Currently, our students are in lab for only six three-hour sessions per semester as opposed to eleven sessions in our previous program. However, the new program was designed so that laboratory time is much more focused. Students now spend the vast majority of their laboratory time conducting experiments versus engaging in tasks like background discussion (now provided in dry labs) and prelab quizzes (taken online).

In our previous program time was not always utilized effectively. For example, students had been given three lab periods to identify unknown compounds in the qualitative analysis lab. Typically, a large majority of students were able to identify their unknown compounds correctly in two lab periods or fewer. Additionally, the Diels-Alder lab in the previous program was allotted two lab periods, but in the new program the essential elements of the lab were condensed into one period. The course revision encouraged us to think critically about what concepts and experiments were absolutely essential to the organic chemistry experience.

However, despite these efforts to most effectively utilize the time that students spent in lab, the total number of hours spent conducting experiments was reduced by about 33% relative to our previous program. This reduction in time, combined with that resulting from a similar program redesign made to our Organic 1 course, undoubtedly had some effect on the development of students' wet lab skills.

There were additional concerns about the format of electronic distribution of a large amount of materials, particularly given that organic chemistry lab is traditionally considered to be a "hands on" course. Since students are completing most of the work for the dry labs independently, it was informally observed that some students treated online assignments more as busy work to complete rather than engaging learning opportunities. This observation raises a larger concern as to whether distribution of materials and assessment of learning made through electronic sources serves to disengage students. Anecdotally, some students commented that the program could feel artificial and impersonal. Our goal was to create a program in which an equilibrium was achieved between electronic and traditional means of instruction and learning.

Along these lines, we have several recommendations for improvement of the program. Our primary recommendation is that the addition of online assignments and writing exercises need not come with the loss of additional wet lab experiments, as we have described. A reasonable adaptation of the program described here could be to increase the number of wet labs while integrating the writing exercises described with each lab. Students would thus be able to practice writing each section of a scientific paper multiple times throughout the semester. For example, students could be assigned to write an abstract for a lab early in the term, receive feedback from the TA, and then write another abstract later. This would allow for measurable assessment of writing technique during the term. However, adding more wet lab assignments would negate some or all of the gains made in reducing the overall cost of the program, required TAs and lab space, and individual TA hours.

Additionally, the nature of the online assignments can continue to be improved in terms of the quality and appropriateness of the questions asked. Sapling's interface allows instructors to easily view a 'heat map' of students' performance on questions. Instructors can quickly identify where the difficulty might lie in specific questions: whether the question is simply challenging or whether it might need to be rephrased for clarity. We utilized this feature to help us identify confusing and difficult questions for students when revising the course from Fall 2010 to Spring 2011.

Conclusions

We developed a laboratory curriculum for the second semester of organic chemistry that included an increased focus on scientific writing and reading. We facilitated this change by using an online virtual platform to provide readings, assignments and questions for students to complete. These revisions allowed for the development of scientific writing skills among students, a key skill set for future scientists, engineers and physicians. In addition, students were able to develop skills using modern technology in conjunction with organic chemistry. Deeper exploration of course topics was possible by assigning online activities that could be completed outside of the laboratory. Logistically, we were able to reduce our labor needs for staffing laboratories and our required laboratory space.

Acknowledgments

We would like to acknowledge the invaluable contributions of Brian Eisenhauer, PhD, and the staff at Sapling Learning during development of the course. Professor Richard MacPhail provided helpful discussion and guidance. Finally, we would like to thank the students in this pilot program for their feedback and patience.

Notes

Readers who are interested in adopting any of the materials described in this chapter are encouraged to contact the corresponding author.

References

1. Norris, S. P.; Phillips, L. M. *Sci. Educ.* **2003**, *87*, 224–240.
2. Peat, M. T.; Taylor, C. E.; Franklin, S. *Innov. Educ. Teach. Int.* **2005**, *42*, 135–146.
3. Wallace, C. *Sci. Educ.* **2004**, *88*, 901–914.

4. American Association for the Advancement of Science. *Science for All Americans: A Project 2061 Report on Literacy Goals in Science, Mathematics and Technology*; AAAS: Washington, DC, 1989.
5. Townsend, M. A. In *The Allyn and Bacon Source Book for Writing Program Administrators*; Ward, I., Carpenter, W., Eds.; Longman: New York, NY, 2002; pp 264−274.
6. Carter, M.; Ferzil, M.; Wiebe, E. N. *J. Bus. Tech. Commun.* **2007**, *21*, 278–302.
7. Motavalli, P. P.; Patton, M. D.; Miles, R. J. *J. Nat. Res. Life Sci. Educ.* **2007**, *36*, 95–102.
8. Krest, M.; Carle, D. O. *Am. Biol. Teach.* **1999**, *61*, 223–227.
9. Moskovitz, C.; Kellogg, D. *Science* **2011**, *332*, 919–920.
10. Lerner, N. *Writ. Commun.* **2007**, *24*, 191–222.
11. Campbell, B.; Kaunda, L.; Allie, S.; Buffler, A.; Lubben, F. *J. Res. Sci. Teach.* **2000**, *37*, 839–853.
12. Peker, D.; Wallace, C. S. *Res. Sci. Educ.* **2011**, *41*, 169–191.
13. Keys, C. W. *J. Res. Sci. Teach.* **1994**, *31*, 1003–1022.
14. Colabroy, K. L. *Biochem. Mol. Biol. Educ.* **2011**, *39*, 196–203.
15. Brown, L. R. *Biochem. Mol. Biol. Educ.* **2006**, *34*, 194–198.
16. O’Connor, T. R.; Holmquist, G. P. *Biochem. Mol. Biol. Educ.* **2009**, *37*, 344–348.
17. Tang, B. L.; Gan, Y. H. *Biochem. Mol. Biol. Educ.* **2005**, *33*, 277–280.
18. Pezzementi, L.; Johnson, J. F. *Biochem. Mol. Biol. Educ.* **2002**, *30*, 376–379.
19. Libarkin, J.; Ording, G. *Cell. Biol. Educ.* **2011**, *11*, 39–46.
20. Krilowicz, B. L.; Henter, H.; KamhiStein, L. *Adv. Physiol. Educ.* **1997**, *17*, S19–S25.
21. Paradis, J. G.; Zimmerman, M. L. *The MIT Guide to Science and Engineering Communication*, 2nd ed.; The MIT Press: Cambridge, MA, 2002.
22. Poock, J. R.; Burke, K. A.; Greenbowe, T. J.; Hand, B. M. *J. Chem. Educ.* **2007**, *84*, 1371–1379.
23. Alaimo, P. J.; Bean, J. C.; Langenhan, J. M.; Nichols, L. *WAC J.* **2009**, *20*, 17–32.
24. Smith, A. C.; Stewart, R.; Shields, P.; Hayes-Kosteridis, J.; Robinson, P.; Yuan, R. *Cell. Biol. Educ.* **2005**, *4*, 143–156.
25. Phadtare, A.; Bahmani, A.; Shah, A.; Pietrobon, R. *BMC Med. Educ.* **2009**, *9*, 27.
26. Dhingra, S.; Chetna, A. *J. Chem. Educ.* **2011**, *88*, 649–651.
27. Wolkenberg, S. E.; Su, A. I. *J. Chem. Educ.* **2001**, *78*, 784.
28. Chittleborough, G. D.; Treagust, D. F. *J. Chem. Educ.* **2007**, *84*, 884.

Chapter 5

Engaging the Masses: Encouraging All Students to “Buy Into” the Organic Chemistry “Program”

N. E. Schore*

Department of Chemistry, University of California, Davis, One Shields Avenue, Davis, CA 95616, USA
***email neschore@ucdavis.edu**

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch005

An overview of some of the challenges facing instructors in the non-major organic chemistry curriculum (including but not limited to “pre-meds”) is presented. Problems that challenge students—both inherent in the course material and associated with the students’ pre-conceived notions—are described. A selection of strategies found useful in dealing with these problems is presented.

Introduction

To the typical college freshman, the prospect of taking general chemistry is scary. If general chemistry is scary to a freshman, organic chemistry is bound to be downright terrifying to the average sophomore. Why is that? More importantly, what can we, *the teachers*, do about it? Perhaps an answer—not necessarily *the* answer, but *an* answer--lies in our recognition that, by its very nature, organic chemistry appears to the typical college sophomore as an utterly alien subject. Written and spoken about in a language that might as well have been downloaded from Neptune. College sophomores are generally pretty intelligent beings. When I stand up in the lecture hall with 500 of them in the seats in front of me, I know I am looking at not some but many people who are without any doubt smarter than I am. *I* get this stuff. Why can’t they? What’s the problem?

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch005

The Problem

Make that plural: Problems.

- Organic chemistry has baggage. Do poorly in o-chem, forget about med school. The intensity of the emotional component can be unlike any that a college sophomore has yet faced. The possibility of medical school is both the carrot and the stick.
- Organic chemistry can't be memorized. But how do *we* convince *them*? Memorizing is easy. The alternative—learning how to solve problems—is harder.
- Organic chemistry is neither fish nor fowl. It is quantitative, sort of. Counting up to eight is a valuable skill. But can one teach an undergraduate student nucleophilicity quantitatively? Hardly. To whit: Fluoride is more basic than bromide so it should be a better nucleophile except of course in a protic solvent that inhibits the small anion by hydrogen bonding, except when the corresponding electrophile is small and hard like a proton, with which the soft bromide ion is a poor match in orbital overlap, blah, blah, blah. As heads used to plugging numbers into a Henderson-Haselbock equation to obtain clear, definitive, quantitative answers to acid-base problems begin to explode, we are left in the same quandary.
- Organic chemistry presents the student with an entire language—much of which is, frankly, unnecessary—but which the student must still learn, because it is the language that organic chemists actually use. And then there's also the language we don't use, despite its endorsement by the IUPAC and ACS nomenclature powers that be. To paraphrase Marston Bates (*1*), scientists have a tendency to believe that they have come up with a new idea, when all they've really done is invent a new word. Use of jargon is a problem that scientists encounter (and cause) regularly.
- Organic chemistry, with its myriad complexities, fascinates us. It doesn't fascinate most of them. College sophomores have other classes, they are working at jobs to pay for school, and they are not proficient at either budgeting their time or even knowing how to establish time-management priorities over the medium term of an academic semester (not to mention an academic quarter). They are unable to leave themselves the time to indulge a fascination for the myriad complexities of organic chemistry, or anything else for that matter. Except, maybe, social media.
- The students want us to tell them what they need to *know*. They *don't* want us to tell them that what we actually want is for them to be able to *do* things with what they know. The following quote is taped to the outside of my office door. Every student who walks into my room for office hours sees it:

> "You just need to be willing to be confused for a while, to sit down and think very hard, and unconfuse yourself."
>
> *Vijay Balasubramanian*
> *Professor of Physics*
> *University of Pennsylvania, 2005*

Organic chemisty is a science. Thus, it is largely problem-solving. I do not try to teach my students organic chemistry. Instead, I try to teach them ways to solve organic chemistry problems. So I am teaching students *how to learn*, rather than feeding them information--simply teaching them.

Problem Solving—The "WHIP" Approach

Breaking down problem solving into "teachable" components can be difficult, more so (ironically) for the smartest of us, because apparent leaps in logic are the gift of those who are the smartest and the most creative. They don't necessarily have to analyze how they solve problems: they simply solve them. Fortunately or not, I did not belong to that category of student, and so problem solving was something I had to break down for myself. I found that the process of solving a problem could involve as many as four distinct stages:

- Identify what the problem is asking. In general chemistry or basic physics, this stage may involve the transformation of a word problem into a solvable formula. In organic chemistry, we instead first need to evaluate the complexity of a problem. Will the solution merely require the application of a single body of information, such as a nomenclature problem? I call this a "What?" problem. Or will multiple pieces of data be needed and integrated? An example of the latter could be a reaction problem where issues of regiochemistry or stereochemistry must be addressed, and therefore the student must implicitly invoke knowledge of the reaction mechanism. I call these "How?" or "Why?" problems, because the words "how" and "why" often appear in the statement of the problem. I tell students to look out for these words as indicators that mechanistic information may be required even if the problem does not explicitly say so.
- Decide how to begin to solve the problem. In nomenclature, identify the stem structure. In synthesis, sketch out a retrosynthetic analysis whose steps involve only known reactions. Which brings us to the third stage:
- Is there any information I lack that I need to find? Do I know all the rules for defining a stem structure? Does my retrosynthesis imply only reactions I have actually learned? This "look up" stage is crucial and often overlooked by students in the course of doing homework for practice. How often do our students breeze through problems ignoring critical pieces of information and go astray as a result? To

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch005

help address this issue I suggest that students try a couple of practice problems with their notes and book open, so that they can be mindful of the relevant issues and fish out needed information. Problems in nucleophilic substitution and elimination are good ones, because several factors must be considered: substrate structure, characteristics of the nucleophile, solvent. Doing a couple of problems with resources open and available can help prevent the student from learning flawed problem solving methods that will need to be subsequently "unlearned," a time-consuming effort that can generate confusion under the time pressure of an examination.

- Proceed step-by-step, without skipping any steps. I tell my students that in reality I know (as in, have memorized) very few mechanisms. In teaching a mechanism at the board, I am relying on my understanding of structure and reactivity to take each mechanistic step to the next one logically, in real time. They at first don't believe me. However, I find that those who do accept that proceeding from one logical step to the next is a worthwhile process are the ones who are ultimately rewarded.

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch005

In the sixth edition of our textbook in organic chemistry (*2*) my colleague Peter Vollhardt and I have described these problem-solving steps in detail in an interchapter "Interlude," complete with illustrative examples. We've named it the "WHIP" approach to problem solving, from the names of the stages (***W***hat is the problem asking? ***H***ow to begin? ***I***nformation needed? ***P***roceed step-by-step, without skipping steps.)

Students inevitably must design problem-solving strategies that best suit their own strengths. The ideas presented in the WHIP approach are intended to present each student with a suggested framework on which to build a methodology that will work for him or her.

Convenient Fiction

What we as practicing organic chemists understand, and what we aim to impart to our undergraduate students are not infrequently two different things. The connections we have learned to make in thinking about the subject often have many intermediate steps, making them very challenging for beginning students to follow. The mechanism of the S_N2 reaction is a good example. Higher-end chemistry majors are perfectly capable of comprehending a legitimate orbital description of the transition state of the process, in which the nucleophile donates electron density into the antibonding (σ*) back-side orbital lobe associated with the carbon–leaving group bond (Figure 1).

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch005

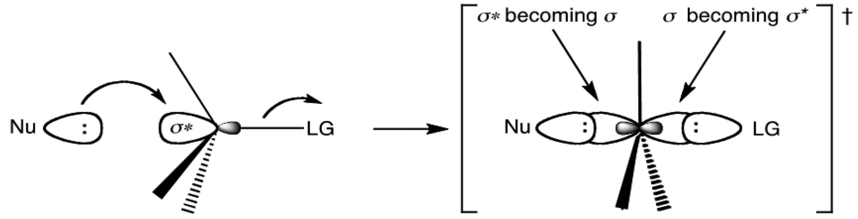


Figure 1. Orbital depiction of the S_N2 transition state.

But what about the typical sophomore pre-meds who make up the majority of the students in our year-long "service" organic chemistry curriculum at UC Davis? I have tried, and the usual response is something like, "What's a σ^* orbital again? And why do I need to know that to become a doctor?" I *could* give a good answer to that question, and in the course of evaluating content for "Organic Chemistry: Structure and Function" Peter and I did consider presenting the proper orbital description. We were, however, strongly dissuaded by comments from numerous reviewers who claimed that the material would be too sophisticated for their students.

We resolved this issue by resorting to a tool that occasionally serves the purpose of giving students a pictorial handle on a process without actually being correct: the "convenient fiction." In the case of the S_N2 reaction, the result (Figure 2) is a depiction of the transition state showing an sp^2-hybridized central carbon whose *p* orbital is simultaneously partially bonded to both the incoming nucleophile and the outgoing leaving group.

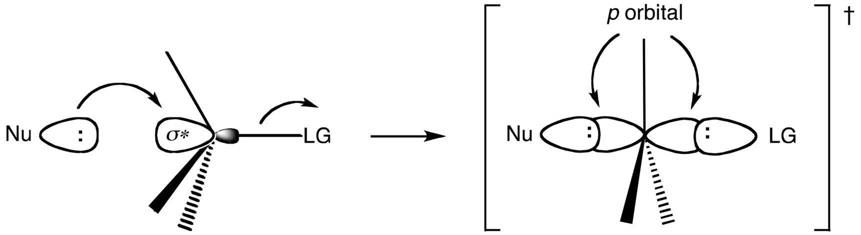


Figure 2. "Conveniently fictional" orbital depiction of the S_N2 transition state.

Astute students may offer the objection that this picture shows a single atomic orbital possessing as many as four electrons, in violation of everything they've learned about atomic structure from the Pauli exclusion principle on up. Curiously, few offer up any comment at all, likely a consequence of the compartmentalization of knowledge that seems to be endemic among our students. So we slide by without the feather-ruffling, not to mention head-exploding, that might accompany the re-introduction of σ^* orbitals to students a year removed from general chemistry.

One might opine that such a strategy is a flagrant falsification that we have no right to inflict upon our students. But the fact is, we do it all the time. Take Lewis structures, for example. Think about how many times we see the phrase "Lewis structure theory" in textbooks. In reality, there is no such thing as "Lewis structure theory" because as a theory it has long since been disproved. The fact that molecules absorb light—making the world visible to us—is enough to confirm that the pictures we draw using Lewis structures are woefully incomplete, and we absolutely need the next level of sophistication provided by molecular orbitals to move closer to a real theory of molecular structure. Why do we persist in using Lewis structures in organic chemistry? Because as a *model*, in contradistinction to a *theory*, they are extremely useful. But regardless of how useful Lewis structures may be, whether we like it or not, they are a structural model with fictional characteristics. These fictional aspects are no more evident than in our use of Lewis structures to depict systems in which π delocalization of electrons gives rise to resonance forms. More recently (*3*) even our ubiquitous use of hybrid orbitals to help rationalize molecular geometry has been called into question.

These examples of convenient fiction differ in degree, but they all possess pedagogical utility in that they allow us to get critical points across without getting sidetracked by very interesting but ultimately distracting issues. Sometimes it's best to just save the discussion of reality for office hour sessions with the most motivated students.

The Timely Mnemonic

Nucleophilic substitution versus elimination—how can we teach students to tell which of the two processes will predominate, given any combination of nucleophile and substrate? A little aside: I have in my hands a classic textbook in organic chemistry (that shall remain nameless) from many years ago. It is the first textbook I taught out of when I began my independent career. Pages 156-158 show potassium hydroxide reacting with an assortment of haloalkanes—primary, secondary, and tertiary—and giving in all cases only alkenes, the products of elimination. Pages 457-460 of the same book show potassium hydroxide reacting with a similar assortment of substrates, from CH_3Br through $(CH_3)_3CBr$, and giving in each case only the alcohol, the product of substitution. Not too many students noticed this self-contradictory situation, but it's *my* job to be able to explain it to them if they ask, isn't it? Of course, the problem is that the textbook was being either inadvertently or deliberately incomplete.

Separating the discussions of elimination and substitution by nine chapters and 300 pages certainly made the deception easier to get away with, and maybe the authors themselves didn't notice, but there is a correct answer, and a learnable process for getting to it. The answer is found in a lengthy series of papers by Ingold in issues of *J. Chem. Soc.* going back to the 1920s. Not that easy to find, but the answers are there.

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch005

In short, the question distills down to three issues: steric hindrance in the substrate, basicity of the nucleophile, and steric bulk of the nucleophile if it is a strong base. Each derives naturally from the relevant features of the four mechanisms involved. Students can handle concepts in threes, and each issue, framed as a question, comes with its own, non-complicated yes/no answer:

1. Is the substrate hindered (sec or tert)?
   NO favors substitution; YES favors elimination
2. Is the nucleophile a stronger base than hydroxide?
   NO favors substitution; YES favors elimination
3. If the nucleophile is a strong base, is it bulky (bearing sec or tert groups on the basic atom)?
   NO favors substitution; YES favors elimination

Thus the mnemonic is, ask three straightforward questions, and the majority rules. The problem is solved for most systems. True, there are grey areas: branched primary substrates fall between primary and secondary in steric hindrance and not surprisingly often give mixtures with strongly basic but non-bulky nucleophiles. However, the point is that questions such as these are well within the manageable range for students of normal ability, once they are provided the means to address them and the reasons the strategies work.

Not all mnemonics derive from chemical principles. The mnemonic for the common names of the dicarboxylic acids was once quite a popular tool. When I teach chemistry majors the rules governing electrocyclic reactions (and when I try to remember them myself) I fall back on the value of a touchdown in American football being 6 points. Thus TD = 6. *T*hermal *D*isrotatory = *6* electrons. Any change in one changes the others accordingly. Dopey, but simple, and it works, which is all that counts in the final analysis.

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch005

They're Going To Talk in Class Anyway, so at Least Get Them Talking about Chemistry

Actually, in a lecture hall with 500+ students, the problem is often getting them to respond to anything. But the following strategy works for me to get them talking about chemistry. Pose a question. Ask if anybody in the class has any idea of how to proceed. Of course, nobody responds. Then say the following:

> OK, everyone. Turn to your neighbor, say hello, and introduce yourself. Now that you've made a new friend, the two of you discuss this question for the next sixty seconds, and then we'll all talk about it.

This approach usually succeeds in getting even a large class into an interacting mode. But don't try this with a group that is difficult to keep under control. Things can get lively—perhaps *too* lively!

Keep It Light, but Make the Road to Success Clear

It is difficult to imagine that any teacher of organic chemistry will be lacking in interesting and even comical anecdotes from his or her undergraduate, graduate, or post-doctoral years. Such stories, especially if they illustrate chemical principles germane to the topic under discussion, can effectively lighten the mood of a class and provide a valuable diversion to the students. Stories can be personal, historical, or just simply funny. If used judiciously these stories can enhance the student's appreciation for the fact that organic chemistry is a science practiced by real people, with tangible goals. At the least they will get the students' attention.

Sometimes stories about former students can illustrate the hard truth about the course to the students as well. One of my favorites relates to a student who managed to survive the first two quarters of the full-year three-quarter sequence, but was finally succumbing in my course. At this point in organic chemistry a lot of concepts are being woven together, and the course can become overwhelming to students who have relied on innate intelligence without really grasping the need to establish strong problem-solving capability.

This particular student achieved a score around 25% on my first midterm and came to me for advice. We went through her exam in detail, and all the expected deficiencies were revealed. She wasn't interpreting questions well ("What is the problem asking?"), she lacked a consistent approach from one problem to another ("How to begin?"), she could not relate a problem to relevant information she'd learned in earlier chemistry courses ("Information needed?") , and even when she had the pieces in place, she would take shortcuts and go astray ("Proceed step-by-step, no skipping steps."). In retrospect, this case was an easy one for me to deal with; the real challenge lay in convincing the student that (a) it would help and (b) it would matter. Fortunately she was very smart—smart enough to recognize what she didn't know and that she needed guidance she could trust. Even in this class of well over 400 students, I rarely see more than about 10% of them in my office hours over the course of the term. But this student didn't miss a single subsequent session. I chose problems and sent her out of the room to work them on her own using the WHIP approach, and modifying it to her own tastes as she proceeded. When she returned we'd pick apart her solutions and look for ways she could improve both in accuracy and efficiency. To make a long story short, she scored over 85% on both the remaining midterm and the final exam (on which the class averages were in the 55-60% range). On the basis of those exam grades alone, her final course grade would have become a B. Not bad, considering the way her quarter had begun.

BUT, I have a little twist that I employ when I determine final course grades. I call it "the algorithm." It's not my idea; it was described to me by my late colleague Charles Nash, a brilliant educator, the first in our department to win the campus-wide Distinguished Teaching Award. The Nash algorithm divides the 200-point final into two 100-point midterm equivalents, identifies and sets aside the lowest exam grade from among the 100-point midterms and the final-derived equivalents, and determines the average of the rest. The low score is subtracted from the average of the remaining (higher) scores, and the *student receives one-half of that difference as bonus points.* The entire procedure implements after the point

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch005

total/final letter grade correspondence has been established, and a student can only go up, never down. It rewards students who improve over the course of the term, and also mitigates the effect of the “one bad day” in that it effectively reduces the weight of the lowest score. The algorithm plugs directly into an Excel spreadsheet:

```
=(((SUM(E2,F2,G2)-MIN(E2,F2,G2/2))/3)-MIN(E2,F2,G2/2))/2
```

where in this example columns E and F gave the scores for midterms 1 and 2, respectively, and the score on the final exam was in column G.

In the case of the student in question, her 25 on midterm 1 was subtracted from her average of 85 on the rest of her midterm-equivalents. She received a bonus of half the difference, 30 points, which moved her from a B to an A as a final course grade.

To be honest, this case was the only one I’ve experienced in 35 years of teaching where a student actually received a bonus amounting to an entire letter grade. Much more often the change is a single +/– increment, such as B to B+ or B+ to A–. Typically some 20-25% of students in a large class realize some grade improvement. But the story, and the algorithm, give students who get off to a poor start some tangible hope that, if they buy into the program, they may see a reward at the end.

I have been asked why I resort to this rather involved method for rewarding improvement as opposed to simply looking though the roster and, say, adding a few points to various students’ totals. The reasons are (a) the method is totally lacking in subjectivity; (b) it rewards students in a way strictly proportionate to their degree of improvement; and (c) it is ‘no-fault’ in that by my not grading on a curve, some students go up, but nobody goes down.

In the final analysis, most students are aware of the stakes but not the numbers. At our place there may be 1000 sophomore pre-meds taking organic chemistry at any given time. In two years’ time, perhaps 250-300 of them will actually apply to a medical school, with 70% of them being admitted on the first try. I present this information to them up front, and follow by making two statements:

“Memorizing alone will not get you an ‘A’.”

“You need to become a problem solver; I will try to show you how.”

How Well Does It Work? Preliminary Results from Learning Assessment

We have begun a program of learning assessment throughout our curriculum. In some courses that takes the form of selecting questions for the final that probe key concepts and monitoring both how well the students do on those at the end of the term and how well this information correlates with the course grade distribution. In the case of beginning organic chemistry, I have also presented variants of those same questions to students as a mini-quiz on day 1. Over the course of two years (some 1000 students), we have results from a random sampling of about 10% of the students.

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch005

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch005

The initial quiz contained five multiple choice questions, one each on nomenclature, stereochemistry, a reaction in connection with a synthesis problem, a reaction mechanism, and spectroscopy, each with four possible answers. The final exam contained five different but parallel questions. The one significant difference was that the reaction/synthesis question on the final also contained a stereochemical component. For the latter we also counted the number of answers that failed to address the stereochemistry but otherwise got the reaction correct. Table 1 below presents the results.

Table 1. Comparizon of results on the "Day 1" quiz vs. similar questions on the final exam of the first quarter of pre-med Organic Chemistry

Question	*Correct on Initial Quiz*	*Correct on Final Exam*
Nomenclature	63%	93%
Stereochemistry	23%	79%
Reaction in synthesis	64%	38% w/stereochemistry; 81% w/out stereochem
Reaction mechanism	22%	51%
Spectroscopy	42%	96%

Students at UC Davis see some organic chemistry in the final quarter of freshman general chemistry. It is not too surprising that many have some grasp of nomenclature at the start of the organic course. Rudiments of structure and reactivity are also presented, although the number of correct answers on the reaction/synthesis question of the quiz may be attributed to good educated guessing. Spectroscopy is a general chemistry topic as well, if not as applied to organic. The percentage of correct mechanism and stereochemistry answers on the quiz represents random guessing.

On the final exam significant improvement is seen in four topics, all five if synthesis ignoring stereochemistry is included. Not surprisingly, students have not fully grasped the need to integrate disparate principles after ten weeks. These results and studies that will follow students' progress through the three-quarter sequence will be used to address ways to improve presentation of course material and how best to improve student engagement in this crucial part of the curriculum.

References

1. The fuller quote as applied to biology is "…we are liable to fool ourselves into thinking we have produced a new thought, when we have only produced a new word… Biocenosis leads easily to biomes and biochores, to ecosystems, ecotomes and seres. These are all lovely words, but they don't really say anything new. The trouble is that the word-coiner, sinking blissfully into his

addiction, gradually loses all communication with the outer world." Bates, M. *The Forest and the Sea*; Time-Life Books: Alexandria, VA, 1960; p 140.

2. Vollhardt, K. P. C.; Schore, N. E. *Organic Chemistry: Structure and Function*; W.H. Freeman: New York, NY, 2010; pp 499−506.
3. Grushow, A. *J. Chem. Educ.* **2011**, *88* (7), 860–862.

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch005

Chapter 6

Use of Neural Scaffolding To Improve Comprehension of Organic Chemistry in a Supplemental Instruction Setting

Connie Gabel,* Dustin Politica, and Rosemarie Walker

Department of Chemistry, Metropolitan State University of Denver, Denver, CO 80217
***Corresponding Author: cgabel@msudenver.edu**

Organic chemistry is a traditionally challenging course for many undergraduate students. Many topics in organic chemistry involve large amounts of information and the development of new skills. Examples of these topics include nomenclature; spectroscopy; addition, substitution and elimination reactions; and stereochemistry. Supplemental instruction (SI) to the professors' lectures provides an opportunity to reinforce organic concepts. Neural scaffolding was used in SI sessions to reduce the information overload and to help develop important skills for students in organic chemistry. Group dynamics facilitated with creating a community of learners. Techniques that separated large topics into smaller pieces allowed students to manage the material more effectively. Examples include distributing nomenclature throughout the course, organizing details about organic reactions in a meaningful manner, and identifying important components of spectroscopy. These techniques distributed the information over time and reinforced previously covered concepts when presenting new material. Repeated opportunities to utilize newly acquired skills improved overall understanding and competency. Results indicate a significant difference in the ABC versus DFWI rate for Organic Chemistry I, but not for Organic Chemistry II. There is also a statistically significant difference in the means of the ACS Organic I first semester exam scores when the SI attendees and the non-SI attendees are compared.

Introduction

Informally ask a doctor, dentist, or other medical professional about the preparation needed to enter these fields, and one vivid memory that all seem to have in common is organic chemistry – and it is often a negative image of how challenging the course was. Many students view organic chemistry as very difficult and have trouble mastering the course.

Although organic chemistry is traditionally a demanding subject for many students (*1–3*), it is a course in which they must be successful to move forward with their education. Organic chemistry is a prerequisite for many graduate and professional programs including medical, dental, and pharmacy schools, and many graduate programs in the life and physical sciences. Additionally, it is often a prerequisite for other important courses like biochemistry and cellular and molecular biology. Thus, struggles with organic chemistry can impair a student's ability to proceed in a chosen career path.

Numerous peer study and supplemental programs have been tried for chemistry and organic chemistry in particular, yet there is little research analyzing them (*2*). The purpose of the study described in this chapter was to design a peer-led, group study program to help address the many pitfalls of organic chemistry by implementing neural scaffolding and integrating various teaching techniques within the neural scaffolding framework.

Supplemental instruction (SI) was implemented in organic chemistry at Metropolitan State University of Denver (Metro State) at the beginning of the Fall 2010 semester. Metro State is a predominately undergraduate institution located in downtown Denver and is a commuter campus with open enrollment policies. The campus attracts non-traditional students, students of color, student veterans, and those from lower socio-economic levels. Of the nearly 24,000 students at Metro State, 32% are minority with 18% Hispanic, making the college an emerging Hispanic Serving Institution. Around 45% of the students are age 25 or older creating unique challenges of juggling job schedules and families with academics. Nearly 32% of Metro State's students are first generation. The SI program increases these students' chances for success in critical classes such as organic chemistry and helps give them the confidence to work toward completion of a college degree.

Neural Scaffolding

Neural scaffolding provides support for students so that they can complete a task that is too difficult without assistance (*4–7*). Scaffolding is a term that has been used since the 1300s to describe a temporary framework of platforms for construction workers (*4*) and was first used in an educational situation by Wood, Bruner, and Ross for teaching reading (*7*). Scaffolding acts like a bridge to get students from where they are to a higher level (*5*, *8*). So, if students are struggling with a concept, the SI leader can determine where there are knowledge gaps and utilize neural scaffolding to increase the students' understanding of the concept. This may be accomplished in a variety of ways such as asking targeted questions, drawing structures on the board, writing chemical reactions, or organizing knowledge in a tabular format. The key is to give the students just enough information so that they can figure it out themselves, but not so much information that the students do not participate in the process. It is important for the students to be involved in the knowledge development (*6*, *8*); this can be accomplished through group work so that the more capable peer assists other peers to better understand a problem or concept.

Fading of the neural scaffolding is important. Once the students have learned to name organic compounds, then they should be expected to do this on their own, but if new aspects of naming such as R,S designations are added, then additional scaffolding may be needed for the new component. Critical features of neural scaffolding include keeping it temporary, supportive, flexible, and appropriate (*4*). Fading, therefore, is necessary for students to learn to gradually manage on their own, and thus a transfer of responsibility occurs (*8*). If however, the scaffolding is removed too quickly, students may not have grasped the concepts well enough to be successful on their own. The key is to provide the maximum scaffolding at the beginning when students are learning a new concept and then gradually remove the scaffolding until the students are competent enough to function independently (*5*).

Frustration control is one of the determiners of how to approach the scaffolding (*8*). If the students are struggling too much to understand a concept, they may drop out of the discussion. On the other hand, if the material is too easy, they become bored. A delicate balance must be maintained between these two extremes so that the difficulty level and the skill level are at the appropriate challenge level (*9*). Breaking the material into more manageable pieces is one approach that can be used to control frustration. Also, a review of the vocabulary can pinpoint gaps in knowledge about important terms used in organic chemistry to further manage the level of difficulty.

Another important aspect of neural scaffolding is reducing the degrees of freedom. This involves simplifying the task by reducing the number of steps to get a solution (*7*). In chemistry, this often means reducing the complexity by concentrating on important components rather than on the entire system. Learning difficult and complex concepts may need to be taken one step at a time, or perhaps a few steps at a time (*10*). For example, rather than focusing on the solvent, catalyst, temperature, equipment needed, extraction steps, etc. for a chemical reaction, the focal point could be on the reactants and primary products. Later, the other pieces could be added as applicable, for instance in a lab setting.

Neural scaffolding includes marking the critical features (*7*). Clarifying critical features is important in understanding chemical concepts. In naming an organic compound, establishing the primary functional group, finding the parent chain, appropriately numbering and naming the parent chain, identifying the substitutents, and determining the appropriate names and numbers for the substitutents are all critical features to arrive at the correct name for the organic compound.

Additionally, demonstrating or modeling is a feature that is often needed in neural scaffolding (*7*, *8*). In organic chemistry, if the students have no idea how to draw a structure for an organic compound, then the SI leader may need to demonstrate how to do this. Alternatively, the SI leader could make a model of the structure and then ask students to draw it.

Challenges of Organic Chemistry

Next, this chapter will examine some of the difficulties students have with organic chemistry, which will lead to a discussion of teaching methods that help students improve their comprehension of the subject. Previous research has reported situations in which approximately 50% or fewer students (of those initially enrolled) are successful in completing the year long sequence of organic chemistry (*1*). Yet, organic chemistry is, as noted above, a gateway course that is required for career paths such as medical, dental, and pharmacy schools and other science, technology, engineering, and mathematics (STEM) professions. At Metropolitan State University of Denver, even with small class sizes of approximately 50 or less, an average of 28% each semester failed to pass Organic I and 21% failed Organic II from Fall 2006 – Spring 2011. During this same time period, the D, withdrawal, F, incomplete (DWFI) rate at Metro State averaged 40% for Organic I and 30% for Organic II. Such high failure rates for organic chemistry must be attributed to something beyond poor study habits and lack of effort from students, particularly in instances in which a high level of student motivation is apparent.

The problems with organic chemistry originate in the complexity (*11*) and uniqueness of the subject matter and the insufficient implementation of appropriate teaching methods to properly address its difficulty (*1*). Student obstacles can arise from a variety of different challenges associated with the subject. Information overload is chief among these challenges. The vast amount of material covered can be tough for students to assimilate in such a short time frame. The unfamiliar vocabulary of organic chemistry presents another challenge. Additionally, much of the material covered is unique in comparison to material covered in other courses students commonly take prior to organic chemistry. In order to become competent with the concepts taught in organic chemistry, students must develop new skills. For example, the ability to draw and visualize molecules in 3D can be particularly challenging for many students. Conformational analysis adds another dimension of complexity (*3*). Also, organic chemistry is a course in which much of the information builds on previous material, so gaps in knowledge can greatly impair a student's performance.

To maximize student success, methods can be utilized to address these challenges. More interactive teaching methods have demonstrated some success in improving student performance (*1*, *12*). However, some challenges can arise when trying to move from the traditional lecture format. Large class sizes make interactive methods more problematic to implement. Many professors may be uneasy with this change in format as a result of unfamiliarity with different teaching methods. Also, some students may be uncomfortable with a change from the format to which they have become so accustomed. It could therefore be beneficial to find a means to retain the traditional lecture while also including interactive methods with the course.

Supplemental Instruction

Supplemental instruction can allow a regular lecture to be maintained while providing an additional opportunity to include other instructional methods. An SI program provides a supplement to the normal course lectures. It presents an opportunity for students to meet outside of class for regular group study sessions and to receive additional help and guidance with their studies. Sessions are led by a peer leader, an upperclassman who has already been successful in the course. SI is attached to a specific section of the course so that SI sessions address the same content that is being covered in lectures for that section. By incorporating group activities and involving students through the use of interactive teaching methods, an SI program can benefit students at all levels.

This study uses neural scaffolding and integrates various methods that have been found to be effective in prior research (*5*, *13*). The key components include avoiding information overload, fading the neural scaffolding, linking prior knowledge, anchoring learning with a schema, integrating questioning techniques, teaching for depth of understanding, and incorporating reverse engineering within the framework of a supplemental instruction program. Additionally, a leadership style that fosters group dynamics helps to establish a community of learners with a focus on constructing knowledge. The judicious use of these in combination has a synergistic effect. Discussion of these techniques and examples of how they have been successfully implemented are provided.

Many supplemental programs have been used to support organic chemistry classes to provide students with additional avenues to learn the material. Traditional lecturing methods have not been effective in addressing the challenges encountered in organic chemistry as evidenced by the large failure rate associated with this course (*1*). In a lecture format, the predominant method for college science teaching, the professor is totally in charge of the class and allows for no input or almost no input from students. In earlier research on learning chemistry concepts (*14*), construction of meaningful knowledge was found to increase depth of understanding. Neural scaffolding can allow students to participate in knowledge construction and a synergistic effect can be achieved under the auspices of a capable leader in a supplemental instruction format. In a discussion of leadership, well-known author Stephen Covey describes what happens with a principle-centered leader to achieve synergy.

> “Synergy is the state in which the whole is more than the sum of the parts. Principle-centered people are synergistic. They are change catalysts. They improve almost any situation they get into. They work as smart as they work hard. They are amazingly productive, but in new and creative ways. In team endeavors they build on their strengths and strive to complement their weaknesses with the strength of others. Delegation for results is easy and natural to them, since they believe in others’ strengths and capacities.”(pg. 37) (*15*)

Methods

General Implementation

At Metropolitan State University of Denver, during the 2010-11 academic year, supplemental instruction was introduced to one Organic Chemistry I section out of five during the fall semester. During the spring semester, SI was continued in one section out of five for Organic Chemistry I and introduced to one section out of four of Organic Chemistry II. None of the sections had recitation sessions, and none of them used computer-based homework. During the five years analyzed in this study including the current academic year, tutoring was available to all organic chemistry students through the Chemistry Department tutoring program and the Metro State Student Academic Success Center.

No attempt was made to change the teaching style of the professor; rather, the focus was on the supplemental instruction and how to best support the students in learning organic chemistry. The professors who taught the classes with SI attached are experienced and have taught organic chemistry for many years. The professors used a traditional lecture method, and one of them incorporated loosely organized small group work during class. The professors who taught the organic chemistry classes with SI attached also taught another section without SI during the academic year in which SI was implemented. The authors' classes did not participate in this research. An outside evaluator also collected data independently to analyze the effectiveness of the SI program and to minimize bias. Analyzing semester grades over a five-year period as well as the use of standardized ACS testing also diminished bias. Other factors that were not controlled, such as concurrent enrollment in another chemistry course, may have contributed to the results.

The SI peer leader was selected for his overall academic performance and his success in Organic Chemistry I and Organic Chemistry II. Training was provided for the peer leader before classes began and in weekly meetings throughout the duration of each semester. The peer leader was supported in his role by a primary supervisor and by the individual professors of the classes to which he was assigned.

The role of the peer leader included regularly attending the organic chemistry class. This allowed the peer leader to be aware of what material was being covered and to direct SI sessions to keep pace with the course. This also provided a review of the course material for the leader. The peer leader planned and organized study sessions and determined meeting times. A major role of the peer leader was to develop activities for SI sessions. The leader determined what material to focus on in group study sessions, generated group and individual activities, provided practice problems, and directed group discussions. In addition, the peer leader held office hours and provided contact information to students so that they could come to the peer leader for individual assistance. This provided an additional point of contact for students, beyond the professor, to discuss the course and receive help.

Lectures were held twice a week for one hour and 50 minutes per lecture; for each day of lecture, a one hour SI session was provided. SI sessions typically reviewed the material covered in the previous course lecture. Since SI sessions were group sessions, and were designed to address the same material being covered in lecture, time to review material from previous weeks was limited. Attendance was voluntary and students were given no incentive beyond receiving additional help with the course. However it was recommended that students attend as many sessions as possible.

Each week during the academic year, the SI Student Peer Leaders, a group comprised of students acting as peer leaders for a selection of science courses, met together in a group with the SI Coordinator. During these meetings, in addition to pedagogical training, the peer leaders worked with the SI Coordinator to analyze issues and to formulate a plan of action. Often they helped each other by offering suggestions for difficult situations they encountered. Because the peer leaders are top science students, they helped generate a list of the most difficult topics they encountered in organic chemistry. These included nomenclature, stereochemistry, determining chiral centers, recognizing enantiomers and diastereomers, drawing Newman and Fischer projections, and organic reaction mechanisms. It is noteworthy that stereochemistry has been shown in other research to correlate highly with academic success in organic chemistry (*2*).

Pedagogical Training

A major difference in the implementation of the SI program at Metro State's Chemistry Dept. compared to many similar programs is the pedagogical training that was provided to the SI Student Peer Leaders. In addition to training prior to the beginning of the semester, the SI Coordinator met weekly with the SI Student Peer Leaders to provide pedagogical training. She also helped the leaders with the implementation of appropriate teaching methods. During the weekly meetings, the SI Coordinator asked for input from the student leaders to assess how the sessions were progressing. At this time, the SI Coordinator made any necessary adjustments and provided suggestions for alternative ways to present complicated topics. Also, the SI peer leaders supported each other by discussing strategies and ways to communicate difficult material. Additionally, the coordinator observed the SI Student Peer Leaders regularly in their sessions to determine how the sessions were going. The SI Student Peer Leaders met individually with the SI Coordinator for feedback, to talk about challenging issues, and to develop content-specific strategies for challenging areas of the curriculum.

Another major difference is the pedagogy implemented in the SI sessions. Some of the pedagogical approaches that were found to work with organic chemistry are given in the next section. Briefly these include a framework of neural scaffolding with fading and the integration of schema theory, the zone of proximal development, Bloom's Taxonomy, group dynamics, the Socratic method, and similar methods to achieve a synergistic result.

Instructional Methods

Neural Scaffolding

In order for the SI leader to be effective and have students actively participating in the SI sessions, neural scaffolding was utilized. Scaffolding is a process of enabling a novice to solve a problem or carry out a task that is beyond the novice's unassisted efforts (*7*). The use of scaffolding with tutorial interactions helps construct knowledge within a social context (*7*). Vygotsky's (*16*) work on socially constructed knowledge has been linked to scaffolding in conjunction with his theoretical concept known as the zone of proximal development. Vygotsky's zone of proximal development references the gap between what a student can achieve alone as compared to what he can do under the guidance of a more capable peer or an expert (*16*). Thus, scaffolding originates from a socioconstructivist learning model. Likewise, this research utilized group dynamics to help students learn organic chemistry. In applying scaffolding to organic chemistry in a peer-led, group study setting, the most important scaffolding functions observed appear to be reduction in the degrees of freedom, marking critical features, frustration control, and demonstration. These scaffolding classifications are based on the earlier work of Wood, Bruner, and Ross (*7*) that indicated the types of support that the more capable person can provide. Sometimes, if students had great difficulty with a concept, the SI peer leader presented that portion of the material to the SI participants again or demonstrated material such as how to draw a structure, etc.

Thus, neural scaffolding was employed in a group study setting to help organic chemistry students bridge gaps in their knowledge with the assistance of a peer who had successfully completed the course and had demonstrated high achievement in the class and on the ACS Organic Chemistry exam. Neural scaffolding was the primary technique implemented in SI sessions. The peer leader received training on neural scaffolding and specific teaching methods by the experienced chemical educator before and throughout the semester. Neural scaffolding incorporates a variety of methods. When employed correctly, neural scaffolding utilizes at least one method to address each major challenge connected to learning specific content, while regularly including students in the learning process. Before examining the technique as a whole, some of the individual methods used will be considered, with the provision of specific examples of how they were used in SI sessions. Some of the methods utilized include framing, chunking, reinforcement, the Socratic method, reverse engineering, and fading.

Framing

High-level knowledge organization is important for learning organic chemistry (*2*); and in earlier research, problem sets were found to strongly correlate with academic success in organic chemistry (*2*). Framing is a method that requires students to outline the steps required to solve a problem. This is done prior to attempting to solve the organic chemistry problem. This method is useful for multiple part problems, particularly those that include various types of material. Students need to learn to relate concepts as an organized network in order for constructivism to work (*17*). They need a framework for building their conceptual networks. This method was used by the peer leader when reviewing how to assign R/S designations. By asking the students what steps would be required to determine the R/S configuration of any chiral molecule, the peer leader guided the students into constructing the following list:

- Identify chiral center
- Assign groups a priority of 1 through 4
- Rotate molecule to place #4 group in back
- Draw arrows from group #1 to #2, from #2 to #3, and from #3 to #1
- Determine if arrows are directed clockwise (R) or counterclockwise (S)

Framing should provide students with a checklist to follow when solving a problem. This checklist will often be sequential but that is not a required criteria. It should, however, provide clear steps that can be easily followed and verified. If the student does not arrive at the correct answer to a problem, they should be able to return to the checklist and determine which step was done incorrectly.

Chunking

There is a limit to the amount of explicit information that the brain can learn at a given time (*18*). Therefore, chunking helps prevent information overload when large amounts of organic chemistry material is being presented. Chunking involves finding ways to group material into more manageable "chunks". This is useful for material with a large amount of information, material with distinguishable sections, and multiple part problems. When chunking is used, students can mentally categorize details more effectively. This helps students manage difficulties with information overload because if the brain becomes overloaded then it cannot continue learning new material at that time (*19*).

In SI sessions, the peer leader used this method with students to help manage the volume of material when alkene reactions were introduced. The peer leader produced a set of categories including Markovnikov, anti-Markovnikov, syn addition, anti addition, nonspecific addition, oxidation, and reduction. Students then constructed tables placing various reagents into the correct categories. Table I was constructed by organic students during an SI session with the assistance of the SI peer leader.

Table I. Reactants Listed by Stereochemistry of the Products of Alkene Reactions[a]

Syn-addition	*Anti-addition*	*Non specific*
H_2 / Pt	Br_2	HBr
OsO_4	RCO_3H / H_3O^+	HCl
BH_3	$Hg(OAc)_2$ / $NaBH_4$	H_3O^+
	Br_2 / H_2O	

[a] Table constructed by SI students showing groupings of alkene reactions based on expected stereochemistry of products.

These groupings helped students to identify important components of reactions and to compare and contrast similar reactions. Using this schematic method guides students in constructing a framework for organizing the information. This method is anchored to schema theory, which indicates that humans utilize frameworks for organizing information in memory (*20–24*). Using this schematic method guides students in constructing a framework for organizing the information.

Linking to Existing Cognitive Structures

Connecting new information to existing cognitive structures helps students with understanding (*20–23*) and a strong correlation has been found with college chemistry and prior knowledge (*25*). Development of neural networks occurs over a period of time through the process of making, developing, and strengthening the neural connections (*18*). The brain examines information for a recognizable pattern or feature and then it searches the established neural networks for a place to put the new information; if the brain detects similarities, it makes it easier to integrate the new information (*26*). A focus on nomenclature was used early in the semester to serve as an anchor for learning material that would be covered later in the semester such as R,S designations for molecules. These cognitive structures were reinforced frequently.

Reinforcement

Reinforcement is a method in which the same material is presented more than once. Practice has been found to be an important part of the learning process (*27*). Frequent repetition of information triggers the brain to store this information so that it is easily accessible (*28*). Reinforcement can help students augment their understanding of key concepts and improve proficiency with recently acquired skills. Reinforcement is also very useful in situations where information overload is common. Information overload often occurs when a great deal of memorization is necessary.

One of the topics for which reinforcement was applied by the peer leader was nomenclature. Students were exposed to nomenclature on multiple occasions in SI sessions. Some of the occasions include an introduction to nomenclature at the start of the semester, reinforcement when learning stereochemistry, and again when substitution/elimination and addition reactions were covered. An example of specific problems given to students is shown in Figure 1. First is an alkyl halide, 2,2-dichloroheptane, that students were given to name at the beginning of the semester. Next is another alkyl halide, (R)-2-bromopentane that was presented when students were covering stereochemistry. This example required students to use previous knowledge for naming an alkyl halide and to incorporate new information to assign R/S designations. Finally, there is an addition reaction in which students were required to name the substrate, 2-hexyne, and product, 2-Z-hexene, while working through the problem.

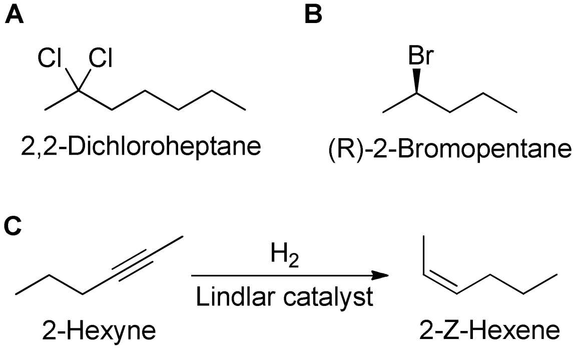


Figure 1. Molecules given to students to name in SI sessions. Molecule A shown in the top left was given to students when nomenclature was introduced. Molecule B was provided to students to name when covering stereochemistry in lecture. The molecules shown in C were given to students to name when covering addition reactions to alkynes in lecture.

In each instance, students reviewed the rules for nomenclature with which they were already familiar. They were then provided with new information when appropriate. As the semester progressed, the students became more proficient at utilizing IUPAC rules for naming molecules.

Socratic Method

The Socratic method is a technique in which students are asked leading questions to help guide them to an answer. Questioning is a motivator of learning where students become motivated in striving for a solution or answer to a question (*29*). Students are provided with enough information to lead them in the right direction, but not so much as to give the answer away. This method can help students become more comfortable with the use of new skills, and help to secure knowledge and understanding of a topic.

In SI sessions, the Socratic method was used frequently by the peer leader. A specific example of when this was used was when the peer leader reviewed acidity of organic compounds. Two molecules were provided such as the ones shown in Figure 2.

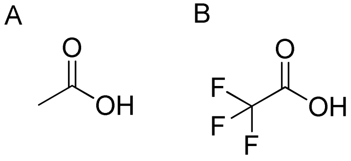


Figure 2. Students were asked to compare the acidity of Molecule A (acetic acid) and Molecule B (trifluoroacetic acid) in an SI session shortly after the topic of acidity had been introduced in lecture.

The goal of the exercise was for the students to determine which molecule would be more acidic. This problem was provided before students had been formally introduced to inductive effects. Students were asked a series of questions beginning with asking them to identify the differences between the molecules. Students identified the fluorine atoms attached to Molecule B as the difference. Students were then asked if this difference is important. They believed it was. The peer leader then asked the students why it is important. They came to the conclusion that it must be related to the electronegativity of fluorine. They were then asked how the electronegativity might affect the acidity. They were initially unsure so it was pointed out by the peer leader that they should consider the conjugate bases of the two molecules. When examining the conjugate bases of the molecules, the students determined that the fluorine atoms would help to stabilize the negative charge on the conjugate base. The peer leader then explained the term induction and provided the actual pKa values for both molecules to illustrate the effect induction has on acidity.

Reverse Engineering

Reverse engineering is a method which involves starting at the answer to a problem and working backwards. It is a useful method for developing and demonstrating a deeper level of understanding and is appropriately applied to key concepts and recently acquired skills. This method was used by the peer leader when reviewing spectroscopy. Students were shown the molecule in Figure 3.

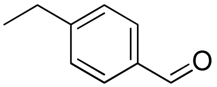


Figure 3. The structure of p-ethylbenzaldehyde was presented to students and students were asked to predict the appearance of the HNMR, and major peaks on the IR and mass spec.

Students were then asked to predict the appearance of various spectral data. For the HNMR, they were asked how many peaks would be expected, where they would show up, and what splitting patterns they would produce. For the IR, students were asked what major absorbances would be expected and where they would be located. For the mass spec, students were asked to identify the molecular weight and the weight of specific fragments. Reproductions of the HNMR, IR and mass spec constructed by students are depicted in Figures 4, 5 and 6 respectively.

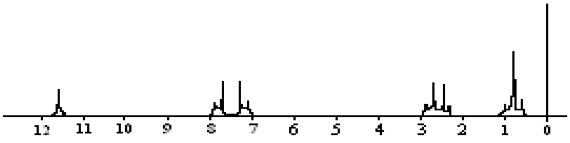


Figure 4. Reproduction of student constructed HNMR predicting peaks of p-ethylbenzaldehyde.

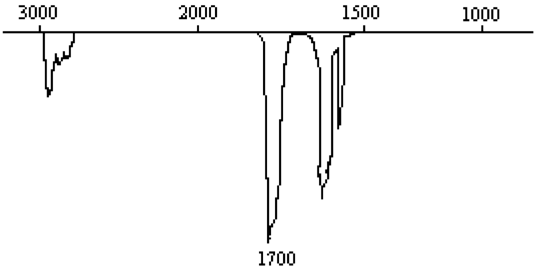


Figure 5. Reproduction of student constructed IR predicting major peaks students had been taught to identify.

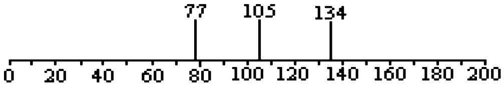


Figure 6. Reproduction of student constructed mass spec predicting major peaks expected for p-ethylbenzaldehyde.

Bloom's Taxonomy

The SI peer leaders focused on the first four levels of Bloom's Taxonomy (*30*). A survey of the SI peer leaders indicated that the material being covered by the professors whose classes had SI attached would best fit within the first four levels of Bloom's Taxonomy. Therefore, the decision was made to emphasize knowledge, comprehension, application, and analysis. Questioning techniques, board work, problem solving exercises, and student questions helped determine gaps in knowledge and ascertain the students' depth of understanding. By asking students to explain a concept or to demonstrate their knowledge of how to solve a problem in small groups or on the board, the SI peer leaders could fairly easily assess level of understanding of that particular concept. With the use of neural scaffolding, the SI peer leader concentrated on building a solid foundation of knowledge by helping the students understand the terms associated with organic chemistry. Organic structures and organic reactions were utilized to assist the students with developing comprehension and applying knowledge to solve organic problems. Framing was used to help students analyze difficult questions with a focus on helping the students to organize the given information, and then to determine what knowledge was needed to solve the problem.

Fading

Fading is a method which can be utilized after a complete scaffold has been previously supplied for specific subject matter. A question or problem is provided in which specific information is intentionally not given to the students and they are expected to fill in the gaps. This is a valuable tool in checking the student's level of understanding and identifying knowledge gaps. This method can incorporate the Socratic method previously described. However, a specific challenge associated with this is to find questions to ask that direct students' thinking without providing information that is too specific.

This method was used in many SI sessions for various topics. One topic for which this was used was hybridization and how hybridization relates to molecular geometries. In class and during SI sessions early in each semester, students were shown a selection of molecules with different hybridizations. The molecular geometries associated with the hybridization types were explained and orbital shapes were shown to students both as drawings and using models. Additionally, associated topics such as pi bonding and resonance were discussed. During a later SI session students were asked to predict the shape of benzene using a skeletal structure drawing. Students were not asked to consider the hybridization of atoms or the types of bonds involved. The students correctly predicted that the molecule would be flat or planar. To confirm that students had not simply memorized that information, and that they possessed a deeper level of understanding, they were asked why they expected it to be so. Again students were not asked or directed to consider hybridization or bond types. Students stated that all the carbon atoms were sp^2 hybridized. Students were then asked why the sp^2 hybridization would cause the molecule to be planar. They indicated that all the carbon atoms should have aligning p orbitals which would allow sharing of electrons through resonance. Using their knowledge of hybridization and resonance, they were then able to conclude that this should be energetically favorable. This exercise was done with the specific intent of checking the students' understanding of hybridization and reinforcing the concepts associated with the topic.

Neural Scaffolding Revisited

As previously mentioned, neural scaffolding can incorporate all of these methods as well as many others. The goal of neural scaffolding is to address all of the identified primary challenges that students face when working with specific topics or subject matter. An example of how this was utilized in SI sessions will be provided to illustrate this concept.

Substitution/elimination reactions is one area of the curriculum that is particularly demanding for organic chemistry students because of the high level of knowledge organization that is required. Neural scaffolding helps the students to organize their knowledge by first making sure that they understand the vocabulary associated with this topic. Next, discussing and explaining the terms assist students with comprehending their meaning and usage so that they can move to applying this knowledge in problems. Creating schema through lists and tables aids students in analyzing and organizing complex information. Providing the scaffolding throughout this process allows students to move from the knowledge level to the analysis level.

Scaffolding is needed because students' understanding of substitution/ elimination reactions can be impacted by a number of challenges. The topic incorporates a high volume of material which can result in information overload. The information includes new and unfamiliar concepts and vocabulary. Attention to multiple components: such as solvent, leaving group, substrate, and substituents is required to solve many problems involving substitution/ elimination reactions. Also, knowledge gaps can significantly impair problem solving abilities with this topic.

In SI sessions, substitution/elimination reactions were given a great deal of attention. One of the first activities regarding these reactions was a group discussion to define and explain many of the new terms introduced with this topic. The SI leader asked students to provide a definition of various terms, including: nucleophile, electrophile, leaving group, substitution reaction, and elimination reaction. After a definition was provided, the students were then asked additional questions. Examples of such questions included asking students to identify the electrophile, nucleophile, and leaving group in a series of reactions and asking them how the saturation of a molecule would change in a substitution or elimination reaction. Following the initial discussion, these terms were then used on a regular basis in SI sessions to help students become comfortable with the new vocabulary.

Another activity included creating a schema to answer the types of questions students were commonly asked regarding substitution/elimination reactions. Students were asked to produce a list of steps needed to answer a substitution/elimination problem similar to those commonly provided in class. These problems usually presented a substrate with reagent(s) and solvent and asked students to determine the product. After the students provided the steps, they were asked to place them in order. This produced the following steps that students could use to help address problems presented:

- Identify the nucleophile or base
- Identify the leaving group
- Determine if the nucleophile or base is "strong"
- Check other factors including carbon substitution and solvent
- Determine reaction type (S_N1, S_N2, E1, E2)
- Determine product of reaction
- Confirm product has proper stereochemical result

The goal of this activity was to help students manage complex questions by breaking them down into steps. Being able to identify these steps helps students that have difficulties knowing how to approach a problem.

Chunking was used in another activity in which students were asked to "chunk" information for each reaction type by creating tables, which grouped the different criteria that favored specific reaction types. This was performed in small groups and the students were allowed to use only notes from class. This activity helped students determine what information was important to focus on and also helped students form mental groupings associated with these reactions. An example of a table constructed by students is shown in Table II.

Table II. Criteria Used to Identify Substitution/Elimination Reaction Type[a]

S_N1	S_N2	*E1*	*E2*
3°>2°>1° C	3°<2°<1° C	3°>2°>1° C	180° H
Good LG	Good Nucleophile	Good LG	Strong Base
Acids w/OH		Acids w/OH	Bulky Base

[a] Example of a table generated by students in SI using grouping criteria to help determine types of reactions.

Concepts and vocabulary were reinforced through practice problems and reverse engineering. Reverse engineering was used by providing students with problems that gave the product of the reaction and the reagent and asked students to provide the initial substrate. An example of this is shown in Figure 7.

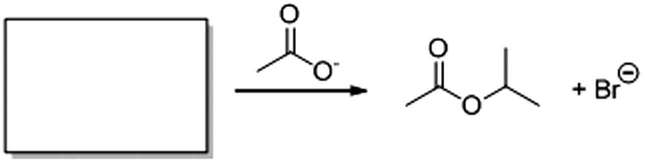


Figure 7. Sample problem given to students in which they were required to identify the initial substrate based on the product and reagent shown.

Throughout all of these activities, the Socratic method was commonly used. Student questions were frequently redirected with only limited guidance provided. This was done to help both the students and the SI peer leader identify the level of understanding possessed and any knowledge gaps present.

The combined use of the various activities and techniques was intended to help reduce the students' level of information overload, improve familiarity and understanding of the concepts and vocabulary, and identify knowledge gaps and individually challenging concepts. These activities were planned to address the major challenges that were identified with this topic while consistently keeping students involved using interactive teaching methods.

Results and Analysis

Data Gathering and Statistical Methods

The Office of Institutional Research and Development provided data. Course reported grades were converted into a four-point scale (A = 4 pts., etc.). The data were tested for significant differences in the distribution of student grades for sections with SI versus those without SI support using the t-test. Two t-tests were conducted at the 95% confidence level: one using historical five-year data and the other using the current academic year that coincided with the academic year with SI supported sections. Student grades from five years of historical data (Fall 2006-Spring 2011) were compared using t-tests in courses without SI support and in courses with SI during the 2010-2011 academic year. A second t-test was conducted for each course using recent comparable courses with and without SI. The t-tests were 2-tailed with unpaired samples, and with unequal variance. Test 1 examined sections for the academic year 2010-2011 with SI versus all 2006-2011 classes without SI while Test 2 analyzed 2010-2011 sections with SI versus 2010-2011 sections without SI. For Organic II, there were no SI sessions during the Fall 2010 semester; therefore, academic support in the form of supplemental instruction was only available for one semester, Spring 2011 for Organic II. The chi-square test of significance was used for the analysis of course completion and grade comparison for historical and current data. Chi-square analyses were course level analyses. Chi-square analysis was used for completes (ABCD) vs non-completes (FWI) with SI versus without SI. Qualitative data were collected using a survey with a Likert scale. The ACS exam scores are the results from the indicated classes.

Quantitative Data

Organic Chemistry I

The five-year grade distribution, as shown in Table III, for 1755 students in Organic Chemistry I classes without SI for 2006-2011 indicates that 60% received an A, B, or C grade and 40% had a D, F, W, or I and 29% had a F, W, or I. The mean is 2.098 on a four-point scale. The standard deviation is 1.314. For the academic year 2010-2011, 293 students without SI received the grades shown in Table III for Organic Chemistry I. Therefore, 58% of these students had an A, B, or C and 42% received a D, F, W, or I with a total of 28% of the grades being a F, W, or I. The mean is 2.135 on a four-point scale. The standard deviation is 1.294. For Organic Chemistry I classes where 73 students had the opportunity to attend SI sessions during the 2010-2011 academic year, 71% received either an A, B, or C and 29% a D, F, W, or I with 19% of those being a F, W, or I. The mean is 2.103 on a four-point scale with a standard deviation of 1.174. These results are summarized in Table III. The ABC versus DWFI rates are graphically represented in Figure 8.

Table III. Organic Chemistry I: Course Grades with SI vs without SI

	2006-2011 Without SI	*2006-2011 With SI %*	*2010-2011 Without SI*	*2010-2011 With SI %*	*2010-2011 With SI*	*2010-2011 With SI %*
A	258	14.7%	45	15.4%	9	12.3%
B	352	20.1%	53	18.1%	14	19.2%
C	446	25.4%	72	24.6%	29	39.7%
D	195	11.1%	40	13.7%	7	9.6%
F	262	14.9%	35	11.9%	9	12.3%
W	230	13.1%	46	15.7%	5	6.8%
I	12	0.7%	2	0.7%	0	0.0%
Total	1755	100.0%	293	100.0%	73	100.0%
ABC	1056	60.2%	170	58.0%	52	71.2%
ABCD	1251	71.3%	210	71.7%	59	80.8%
DFWI	699	39.8%	123	42.0%	21	28.8%
FWI	504	28.7%	83	28.3%	14	19.2%

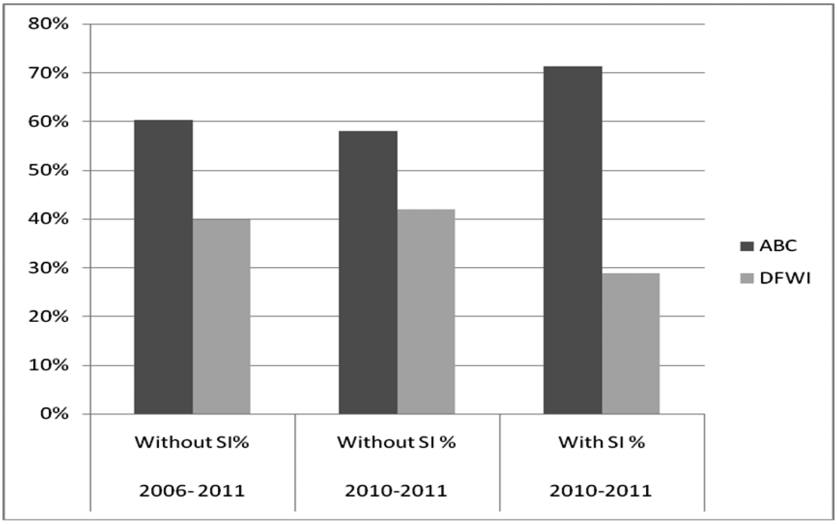


Figure 8. Comparison of ABC vs. DWFI grade categories for students enrolled in Organic Chemistry I without SI during a five- year interval,without SI during the 2010-11 academic year, and with SI during the 2010-11 academic year.

Two 2-tailed t-tests with unpaired samples and unequal variance were used to compare the Organic Chemistry I data for statistically significant differences in the means. The first t-test compared the historical data from 2006-2011 without SI to the 2010-2011 academic year with data from the classes with SI. The result of $t = 0.031$ ($\alpha = 0.05$) indicates there is not a statistically significant difference between the means of the data sets. The second t-test compared the data from the current academic year for the classes with SI versus those without SI. The result of $t = 0.184$ ($\alpha = 0.05$) indicates that there is not a statistically significant difference between the means.

The chi-square test was used to determine whether the observed proportions of Organic Chemistry I grade distributions differed from those expected. Historical distribution of ABC & DFWI for 2006-2011 classes without SI was compared with the 2010-2011 academic year for classes with SI. The chi-square result of 3.68 is only statistically significant at $\alpha = 0.10$. The ABCD versus FWI grade distributions were compared historically for 2006-2011 classes without SI versus the 2010-2011 academic year for classes with SI. The chi-square result of 3.54 is only statistically significant at $\alpha = 0.10$. Another chi-square test was used to compare the ABC and DFWI grade distribution for the 2010-2011 academic year for the Organic Chemistry I classes without SI versus those with SI. The chi-square of 5.06 is statistically significant at $\alpha = 0.025$. The comparison of the ABCD and FWI grade distributions for the 2010-2011 academic year Organic Chemistry I classes without SI versus those with SI is a chi-square of 2.93, which is only statistically significant at $\alpha = 0.10$.

Table IV shows the five-year grade distribution for Organic Chemistry I from 2006-2011 including those students who had SI available during the 2010-2011 academic year. Of 1828 students, 61% received an A, B, or C and 39% had a D,W, F, or I. The five-year grade distribution data are represented graphically in Figure 9.

Table IV. Organic Chemistry I Five-Year Grade Distribution

	Number	*Percentage*
A	267	14.6%
B	366	20.0%
C	475	26.0%
D	202	11.1%
F	271	14.8%
W	235	12.9%
I	12	0.7%
	1828	100%

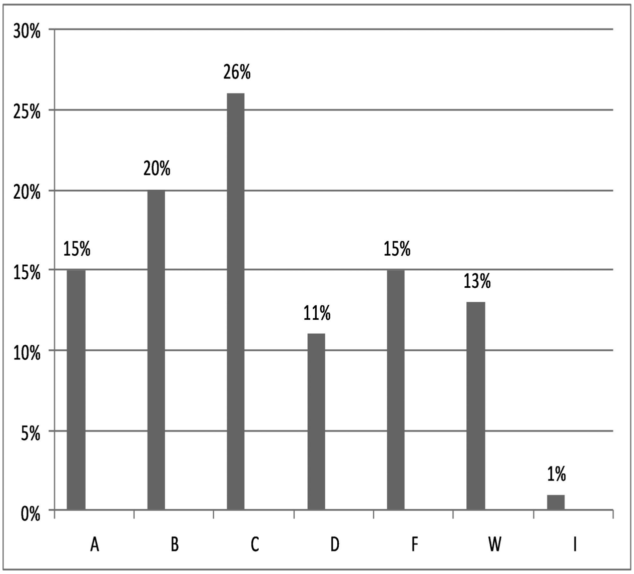


Figure 9. Organic Chemistry I Grade Distribution Over Five Years (N = 1828)

Students took the first semester ACS Organic I exam at the end of the semester. Students who attended SI were compared to those who did not attend SI. The mean for the SI attendees was 38 and the non-SI mean was 34. A two-tailed t-test with unpaired samples and unequal variance was used to compare the means for a statistically significant difference. The result of $t = 2.13$ ($\alpha = 0.05$) indicates there is a statistically significant difference between the means of the SI students when compared to the non-SI attendees during the 2010-2011 academic year.

Organic Chemistry II

For Organic Chemistry II, the course grades from 2006-2011 are depicted in Table V. For the 876 students without SI, 71% received an A, B, or C and 29% a D, F, W, or I. The mean is 2.35 on a four-point scale, and the standard deviation is 1.23. During the 2010-2011 academic year, course grades for the 156 Organic Chemistry II students without SI indicate that 66% received A, B, or C and the DWFI rate is 34% with 25% receiving a F, W, or I. The mean is 2.24 on a four-point scale. The standard deviation is 1.27. SI was only offered to one section of Organic Chemistry II students, and this occurred during the 2011 Spring Semester. The course grade distribution for these 30 students is as indicated in Table V with the following percentage breakdown: 63% ABC, 37% DWFI, and 23% FWI. The mean is 2.11 on a four-point scale. The standard deviation is 1.28. These results are summarized in Table V.

Table V. Organic Chemistry II: Course Grades with SI vs without SI

	2006-2011 Without SI	*2006-2011 With SI %*	*2010-2011 Without SI*	*2010-2011 With SI %*	*2011 With SI*	*2011 With SI %*
A	155	17.7%	27	17.3%	4	13.3%
B	216	24.7%	28	17.9%	7	23.3%
C	248	28.3%	48	30.8%	8	26.7%
D	73	8.3%	14	9.0%	4	13.3%
F	90	10.3%	18	11.5%	4	13.3%
W	89	10.2%	21	13.5%	3	10.0%
I	5	0.6%	0	0.0%	0	0.0%
Total	876	100.0%	156	100.0%	30	100.0%
ABC	619	70.7%	103	66.0%	19	63.3%
ABCD	692	79.0%	117	75.0%	23	76.7%
DFWI	257	29.3%	53	34.0%	11	36.7%
FWI	184	21.0%	39	25.0%	7	23.3%

The chi-square test was used to compare the ABC and DFWI 2006-2011 historical grade distributions in classes without SI versus the current academic year classes with SI. The chi-square of 0.93 is not statistically significant at $\alpha = 0.05$. A second chi-square test compared the ABCD and FWI grade distribution for 2006-2011 Organic Chemistry II classes without SI versus the current academic year classes with SI. The chi-square of 0.072 is not statistically significant at $\alpha = 0.05$. In a third chi-square test, the ABC and DFWI grade distributions were compared for the current academic year classes with SI versus those without SI. Again the chi-square result of 0.12 is not significant at $\alpha = 0.05$. Another chi-square test compared the ABCD and FWI grade distributions for the current academic year for Organic Chemistry II classes with SI versus those without SI. The chi-square of 0.064 is not significant at $\alpha = 0.05$. Two 2-tailed t-tests with unpaired samples and unequal variance were used to compare the data for statistically significant differences in the means for Organic Chemistry II classes. The first t-test compared the historical data from 2006-2011 without SI to the 2010-2011 academic year with data from the section with SI. The result of $t = 1.10$ ($\alpha = 0.05$) indicates there is not a statistically significant difference between the means of the data sets. The second t-test compared the data from the current academic year for the classes with SI versus without SI. The result of $t = 0.48$ ($\alpha = 0.05$) indicates that there is not a statistically significant difference between the means.

Table VI summarizes the 2006-2011 five-year grade distribution for the 906 Organic Chemistry II students including the one section that was offered SI during Spring 2011. The data indicate that of the 906 students the percentage breakdowns are as follows: 70% ABC, 30% DFWI, and 21% FWI. The data are graphically depicted in Figure 10.

Table VI. Organic Chemistry II Five-Year Grade Distribution

	Number	*Percentage*
A	159	17.5%
B	223	24.6%
C	256	28.3%
D	77	8.5%
F	94	10.4%
W	92	10.2%
I	5	0.6%
	906	100%

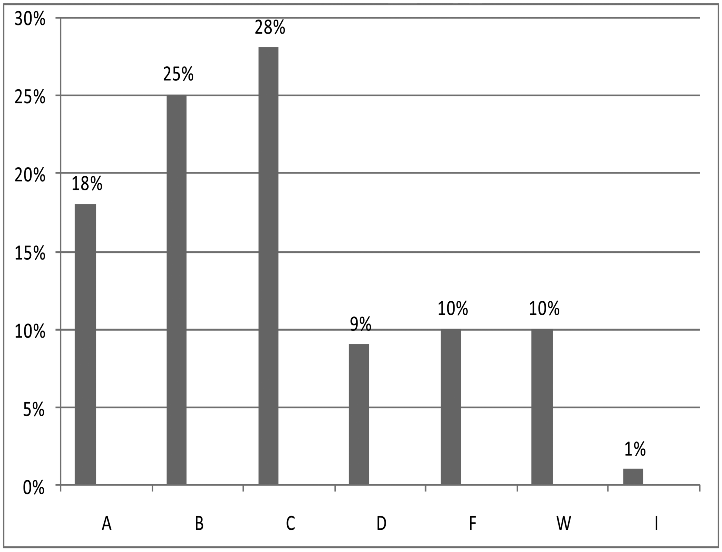


Figure 10. Organic Chemistry II Grade Distribution Over Five Years (N = 906)

Qualitative Data

Triangulation with qualitative and anecdotal data from both students and professors indicate noticeable and measureable differences in the depth of understanding and student performance on in-course tests and quizzes. Qualitative data indicate strong support for SI in organic chemistry for students who could take advantage of the SI sessions. The Likert survey results indicate that 30% of the students always or frequently attended the SI sessions. Of the students who did not attend SI or rarely attended SI, 63% cited schedule conflicts with work or another class as the reason that they did not attend SI. Only two students gave negative comments with one stating that "I felt I studied better alone." The other student wrote "I didn't attend all the time because when I did go it didn't make a big difference in my understanding or grade." Of the students who regularly attended SI sessions, 78% agree or strongly agree that SI helped them to get a better grade in organic chemistry. On the question asking if SI helped them to obtain a better understanding of organic chemistry, 100% of the regular attendees agree or strongly agree that SI did help them gain a better understanding of organic chemistry. Of the regular attendees, 88% indicate that SI helped them to prepare for tests and quizzes and 100% believed that SI helped them learn how to solve organic chemistry problems. Likewise all of the regular attendees responded that the SI peer leader helped them to better understand organic chemistry. Students who regularly attended organic chemistry SI sessions made the following comments when responding to what they liked best about SI:

- Student 1: "I like our SI leader. He is great at making organic chemistry easier to understand."
- Student 2: "The SI leader was incredibly helpful."
- Student 3: "Additional informal time to ask questions; also an alternative explanation often helped."
- Student 4: "The SI leader answered all questions and really helped me in understanding the material."
- Student 5: "That I learned more in the sessions than the class itself."
- Student 6: "Helps slow down the learning process/concepts."
- Student 7: "Gives extra help."
- Student 8: "The one on one help."
- Student 9: "It's nice to get clarification on hard topics and a second voice to explain concepts."

Regarding how SI can be improved, a number of students wanted the SI sessions to be longer or offered at other times so those with scheduling conflicts could attend. One student commented, "There should be SI groups for every organic chemistry! I have some friends who would love it!" Another student wrote, "I am really lucky to have these extra sessions because I feel as though I really gained a great amount of organic chemistry knowledge. Thank you for helping me better understand organic chemistry!" Additional comments include "It is a wonderful program, and I hope this program continues to be available for future students." "It has been extremely valuable in my understanding of O Chem."

Discussion

During the 2010-2011 academic year, for Organic Chemistry I, 71% of students in the class with SI attached received an A, B, or C versus 58% of the students in the classes without SI who received an A, B, or C; this is a difference of 13%, and the chi-square of 5.06 is statistically significant at $\alpha = 0.025$ when the ABC and DFWI percents were compared, indicating that there is a difference. The percentage of students with SI available who withdrew from the class or received a F or I was 19% compared to 28% in classes without SI; this is a difference of 9% but is only statistically significant at $\alpha = 0.10$ with a chi-square of 2.93. Therefore, the trend is that more students complete Organic Chemistry I with an A, B, or C when SI is attached to the class. Comparing the standard deviations of the means for Organic Chemistry I semester grades indicates that the trend is less deviation from the mean in classes that had SI attached. For the classes with SI attached the standard deviation is 1.174 versus 1.314 historically for the 2006-2011 time period and 1.294 for the 2010-2011 academic year. The t-test comparison of the means for the ACS Organic I exam indicates a statistically significant difference between the SI students and the non-SI attendees.

Although the quantitative data did not indicate a significant difference in grade distribution when ABCDF grades were compared statistically for Organic Chemistry II, students reported an increase in depth of understanding and better preparation for tests. With limited resources, the decision was made to focus on Organic Chemistry I since offering SI in these classes seemed to make a bigger difference, which matches with the results found in other research (*31*). Perhaps the Organic Chemistry II students have developed more successful methods for studying organic chemistry. The enrollment in Organic Chemistry II is only 50% of that for Organic Chemistry I during the 2006-2011, five-year time period that was analyzed in this study. The aggregate data show that in five years, 638 students finished Organic Chemistry II with an A, B, or C. When compared to the 1828 enrolled in Organic Chemistry I during this same time period that means only 35% on average finish Organic Chemistry II with an A, B, or C grade. The ABCD completion rate increases the numbers to 715 and 39% over this five-year time frame. Nearly one out of every three students beginning Organic Chemistry II received a D, W, F, or I at the end of the semester. Also, perhaps those who were not very successful in Organic Chemistry I did not take Organic Chemistry II because during the five years data were analyzed, 1828 students enrolled in Organic Chemistry I while only 638, or 35% of the number enrolled in Organic I completed Organic Chemistry II with an A, B, or C grade.

The students who voiced the negative comments on the Likert survey were not regular SI attendees; therefore, with regular attendance, they too may have benefited from SI. The qualitative data signify overwhelming support for SI and indicate that students have a better understanding of organic chemistry because of SI. Students also indicate that they want SI offered for more classes and more hours per week than it is currently offered. At the end of the semester for Organic Chemistry I, students expressed a strong interest in having SI available for Organic Chemistry II.

Qualitative data also indicate that neural scaffolding made possible the construction of tables, spectra, and molecular structures for better understanding of the material presented. Samples of these are found earlier in the chapter. Using the questioning techniques embedded within the Socratic method provided a neural scaffold to help the students achieve a greater depth of understanding and also allowed the peer leader to probe for gaps in knowledge and misinformation.

The comparison of the ACS final exam scores for Organic I indicate that the students who attended SI did comprehend the material better than those who did not attend SI. Thus, the quantitative data support the qualitative data in this regard.

Because attendance was voluntary, perhaps the students who were more motivated attended SI. However, tutoring was available to the organic chemistry students in all of the sections. Thus, the motivated students could seek tutoring whether SI was attached to their section or not. Tutoring was available for the entire five-year period included in this study.

Conclusion

Students benefited from having SI attached to their organic classes as evidenced by the statistically significant difference in the course completion rate at the ABC level for Organic Chemistry I, the statistically significant difference between the means on the ACS Organic I exam, and the positive qualitative results obtained from the Likert surveys. Supplemental instruction appears to offer many benefits over traditional tutoring according to observations by the professors and feedback from students. Among these observations are that the SI Student Peer Leader can provide more focused support to the organic chemistry students because the SI Student Peer Leader attended the lecture with the students; and therefore, can better help the organic chemistry students understand the concepts covered in the lecture. The SI Student Peer Leader only covers one class taught by one professor; and therefore, does not provide the wide range of assistance to students required by traditional chemistry tutors. Traditional tutors may be trying to answer student questions associated with General Chemistry I, General Chemistry II, Organic Chemistry I, Organic Chemistry II, and other chemistry classes in addition to answering questions about a course he or she is familiar with, but taught by various professors who have a different emphasis on material than did the professor from whom the tutor took the course. A tutor has to deal with all of these variables within a short time frame. Targeting specific difficult classes takes some of the load off of the chemistry tutors and provides more direct support for the students in the targeted classes. There are of course higher costs connected with providing SI over traditional tutoring, and this will be one of the challenges associated with continuing Supplemental Instruction at Metro State. However, having SI attached to the classes that have been shown to be the most difficult, such as organic chemistry, can keep students in these classes as the higher completion rate of this research indicates. Then, there is an overall cost savings because the student does not have to retake organic chemistry again and yet again, and the professors do not have to keep re-teaching the material to the students who failed organic chemistry and are retaking it for a second or third time. Therefore, Metropolitan State University of Denver Chemistry Department plans to continue to offer supplemental instruction for organic chemistry.

The peer leader observed that there were numerous gaps in knowledge and much time was spent bridging these gaps. The next step is to construct a pre-test to assess whether students can transfer learning to organic chemistry from the concepts that were presented in general chemistry. Also, developing curriculum designed to help organic students bridge the knowledge gaps as indicated by the pre-test is another logical step in our program's progress.

A limitation of this study is the utilization of the end of semester grades. These grades are limited in the amount of details about the academic performance of the organic chemistry students that they provide. If for example, most students receiving a B grade had historically received that grade for an 80%, but in 2010-2011 most B students received that grade for an 89%, this shift would not be reflected in the ABCD grading scale. Therefore, with the use of end of semester grades, statistically significant differences may not have been detected even though these differences may have existed. Perhaps this could explain why a statistically significant difference is not apparent for Organic Chemistry II even though students did indicate that SI was a big help to them. Also, with Organic Chemistry II, the sample size is limited because SI was only offered for Organic Chemistry II for one semester for one section.

The techniques that were incorporated within the neural scaffolding in Metro State's supplemental instruction program appeared to benefit students. They reported that SI was helpful, and they liked working with the SI Student Peer Leaders. They expressed repeatedly that supplemental instruction helped them to improve their comprehension of organic chemistry. The professors who participated in the SI program observed a noticeable difference in student understanding of the material and improvement in grades.

Professors can incorporate the neural scaffolding and other teaching techniques discussed in this chapter into their organic chemistry classrooms in an interactive teaching model. Incorporating neural scaffolding in lecture should improve the teaching of organic chemistry. This could be accomplished by using interactive teaching methods similar to those used in SI sessions. These interactive teaching methods allow the professor to check for student understanding and for gaps in knowledge. For example, having organic chemistry students draw structures for organic molecules on the board quickly assesses whether they can accomplish this with or without assistance. Offering scaffolding as necessary encourages them to continue participating in board work exercises. Regularly allowing students time to work in pairs and structured groups provides an occasion for more capable peers to instruct others. Constructing tables of organic chemistry concepts with students gives them an opportunity to organize their knowledge. Guided questioning is very effective in encouraging students to participate in the construction of knowledge. Providing neural scaffolding as needed fosters a classroom culture that helps create a community of learners.

Neural scaffolding provides a means for students to engage in an interactive teaching model that otherwise would not be possible. In Supplemental Instruction sessions, the SI peer leader can help the organic chemistry students to construct tables, spectra and similar means of representating the material to achieve a deeper level of understanding. The high level of knowledge organization that is required in organic chemistry is often overwhelming without the help of the SI peer leader. Constructing schema for problem solving such as determining leaving groups, identifying nucleophiles, deciding if bases are weak or strong, and checking for other factors such as solvent, reaction conditions, etc. provides students with a method for organizing knowledge. Once the students have chunked this information together, they are more likely to be able to use it. Having the knowledge in unconnected, isolated pieces makes it difficult for students to solve complicated problems such as those presented in organic chemistry. The Socratic method allows the SI peer leader to scaffold the concepts through appropriate questions; thus, providing a process to achieve better comprehension. Frequent reinforcement is important for retention. Connecting to prior knowledge helps students to anchor their learning of important organic chemistry concepts. Fading the neural scaffolding assists in moving students away from dependence upon the SI peer leader. The neural scaffolding method presented in this chapter provides an effective, interactive teaching model for peer-led supplemental instruction to achieve better comprehension in organic chemistry. This pedagogical model could be used in other peer-led group study programs.

Biographies

The first author is an experienced chemical educator and organic chemistry professor who has successfully applied the techniques and theories referenced in this chapter in her own chemistry classroom. Many of these techniques she has also successfully helped others incorporate into their own classrooms with difficult topics such as science inquiry. She is also the Supplemental Instruction Coordinator. The second author was the Supplemental Instruction Student Peer Leader. Author three is the Strides Toward Encouraging Professions in Science (STEPS) Director who initiated the Supplemental Instruction program described in this chapter and is a chemistry professor as well.

Acknowledgments

The authors would like to acknowledge Susan Schelble and Russell Barrows, the professors who supported having SI attached to their organic chemistry classes. Likewise the authors are appreciative of the students who participated in the SI program and gave their comments for this research. Supplemental Instruction at Metropolitan State University of Denver was instituted as part of the Strides Toward Encouraging Professions in Science (STEPS) program with funding through National Institutes of Health grant 5R25GM058381-07 and Grant 3R25GM058381-07S1 funded by ARRA monies. Additionally, the authors would like to acknowledge the general support provided by the Metropolitan State University of Denver Chemistry Department, the Metropolitan State University of Denver School of Letters, Arts & Sciences Dean's Office, the Community College of Denver Center for Math and Science, and the Auraria Higher Education Center.

References

1. Paulson, D. Active Learning and Cooperative Learning in the Organic Chemistry Lecture Class. *J. Chem. Educ.* **1999**, *76*, 1136–1140.

2. Szu, E.; Nandagopal, K.; Shavelson, R. J.; Lopez, E. J.; Penn, J. H.; Scharberg, M.; Hill, G. W. Understanding Academic Performance in Organic Chemistry. *J. Chem. Educ.* **2011**, *88*, 1238–1242.
3. Whitlock, C. A Modeling Exercise for the Organic Classroom. *J. Chem. Educ.* **2010**, *87*, 1350.
4. Benson, B. K. Coming to Terms. *English Journal* **1997**, *86* (7), 126–127.
5. Gabel, C. Impact of the Reform Efforts on K-12 Science Inquiry: A Paradigm Shift. In *The Impact of State and National Standards on K-12 Science Teaching*; Sunal, D. W., Wright, E. L., Eds.; Information Age Publishing: Greenwich, CT, 2006; pp 215−256.
6. Searle, D. Scaffolding: Who's Building Whose Building? *Language Arts* **1984**, *61*, 481–483.
7. Wood, D.; Bruner, J. S.; Ross, G. The Role of Tutoring in Problem Solving. *J. Child Psychology Psychiatry* **1976**, *17* (2), 89–100.
8. Wood, D.; Wood, H. Vygotsky, Tutoring and Learning. *Oxford Review of Education* **1996**, *22*, 5–16.
9. Arce, J.; Betancourt, R. Student-designed Experiments in Scientific Lab Instruction. *J. College Science Teaching* **1997**, *27*, 114–118.
10. Bliss, J.; Askew, M.; Macrae, S. Effective Teaching and Learning: Scaffolding Revisited. *Oxford Review of Education* **1996**, *22*, 37–61.
11. Whitesides, G. M.; Ismagilov, R. F. Complexity in Chemistry. *Science* **1999**, *284*, 89–92.
12. Cooper, M. M. Cooperative Learning. *J. Chem. Educ.* **1995**, *72* (2), 162–164.
13. Gabel, C. The Use of Scaffolding to Teach Students to Design Inquiry-Based Experiments. Presented at SWARM Division Meeting of AAAS, Sante Fe, NM, April, 1999.
14. Taber, K. S.; Watts, M. Constructivism an Concept Learning in Chemistry: Perspectives from a Case Study. *Research in Education* **1997**, *58*, 10–19.
15. Covey, S. R. *Principle-Centered Leadership*; Simon & Schuster: New York, 1991.
16. Vygotsky, L. *Mind in Society: The Development of Higher Psychological Processes*; Harvard University Press: Cambridge, 1978.
17. Glynn, S. M., Yeany, R. H., Britton, B. K., Eds. *The Psychology of Learning Science*; Lawrence Erlbaum: Hillsdale, NJ, 1991.
18. Jensen, E. *Brain-Based Learning*; The Brain Store: San Diego, 2000.
19. Jensen, E. Moving with the Brain in Mind. *Educational Leadership* **2000**, *58* (3), 34–37.
20. Anderson, R. C.; Spiro, R. J.; Anderson, M. C. Schemata as Scaffolding for the Presentation of Information in Connected Discourse. *Am. Educ. Res. J.* **1978**, *15* (3), 433–440.
21. Gallini, J. K. Schema-based Strategies and Implications for Instructional Design in Strategy Training. In *Cognitive Strategy Research: From Basic Research to Educational Applications*; McCormick, C. B., Miller, G. E., Pressley, M., Eds.; Springer-Verlag: New York, 1989; pp 239−268.
22. Glaser, R. The Role of Knowledge. *American Psychologist* **1984**, *39* (2), 93–104.

23. Glaser, R. The Maturing of the Relationship between the Science of Learning and Cognition and Educational Practice. *Learning and Instruction* **1991**, *1* (2), 129–144.
24. Peterson, P.; Comeaux, M. Teachers' Schemata for Classroom Events: The Mental Scaffolding of Teachers' Thinking during Classroom Instruction. *Teaching & Teacher Education* **1987**, *3*, 319–331.
25. Novak, J. D. Learning Science and the Science of Learning. *Studies in Science Education* **1988**, *15*, 77–101.
26. Westwater, A.; Wolfe, P. The Brain-Compatible Curriculum. *Educational Leadership* **2000**, *58* (3), 49–52.
27. Meyer, A.; Rose, D. H. Universal Design for Individual Differences. *Educational Leadership* **2000**, *58* (3), 39–43.
28. Holloway, J. H. How Does the Brain Learn Science? *Educational Leadership* **2000**, *58* (3), 85–86.
29. Harpaz, Y.; Lefstein, A. Communities of Thinking. *Educational Leadership* **2000**, *58* (3), 54–57.
30. Bloom, B. *Taxonomy of Educational Objectives*; McKay: New York, 1956.
31. Rath, K. A.; Peterfreund, A.; Bayliss, F.; Runquist, E.; Simonis, U. Impact of Supplemental Instruction in Entry-Level Chemistry Courses at a Midsized Public University. *J. Chem. Educ.* **2012**, *89*, 449–455.

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch007

Chapter 7

What's Wrong With Carbonyl Chemistry?

Scott T. Handy*

Department of Chemistry, Middle Tennessee State University, Murfreesboro, TN 37132
***shandy@mtsu.edu**

In general, students struggle with the sections of Organic Chemistry that pertain to the properties, reactivity, and synthesis of carbonyls. Although each and every new Organic text claims to have a new and different approach to teaching carbonyl chemistry, the results, in terms of student performance on exams and retention of material, appear to be largely the same regardless of the text. In struggling with how to improve student comprehension and retention of carbonyl chemistry, one possible source of the problem was identified as its location. In most cases, it is covered near the end of the second semester of a two semester long sequence of Organic Chemistry. As a result, it could be simple fatigue that is part of the problem. To study this hypothesis, Organic II has been taught with a revised order: carbonyl chemistry at the start of the second semester and aromatic chemistry at the end.

Introduction

Organic Chemistry is a challenging course for many students. Many approaches have been tried over the years to make it more accessible to the typical student, in particular the increasing emphasis on biological applications in virtually every textbook. In addition, various pedagogical approaches have been applied to Organic Chemistry (*1–3*). While continued efforts to address the problem students have with the class overall are certainly important, I have noted that students seem to have a particularly serious issue with carbonyl chemistry.

The most obvious means of identifying that students have an issue with carbonyl chemistry is by examining the class average on exams throughout the second semester of Organic Chemistry. Although there are some differences from instructor to instructor, a fairly typical sequence involves the following main topics: radicals, dienes, aromatics, carbonyl addition and substitution, carbonyl condensations (aldol chemistry), and biomolecules. In my class, I cover all of these topics except biomolecules (which is integrated in the appropriate sections of other chapters – for example, amino acid chemistry is included in with carbonyl substitutions). The division of these topics in exams for my class can be seen in Table I.

Table I. Exam and Topic Breakdown

Exam Number	*Topic*
1	Radicals
1	Dienes
2	Aromatics
3	Carbonyl Addition/Substitution
4	Carbonyl Condensations (Aldol)

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch007

Even a quick glance at the exam average information in Figure 1 shows that students, on average, start the semester off well and then dramatically have issues when carbonyl chemistry comes around. This is an unfortunate situation for a number of reasons. Of course, it does not help students earn a good grade in the class (although many still do). More importantly, though, carbonyl chemistry is really the single most important topic for the majority of students taking Organic Chemistry. A good understanding of carbonyl chemistry is important for success and understanding in Biochemistry and Molecular Biology – courses that virtually every student in Organic will take in the future. This material also appears heavily on standardized tests, including MCAT, DAT, PCAT, etc. As a result, it will have a disproportionate influence on their future success.

Indeed, the recently released AAMC/HHMI report on creating scientifically literate physicions specifically highlights carbonyl chemistry as a key part of Organic Chemistry that is essentially for quality preparation of future physicians (*4*). Carbonyl chemistry also receives significant emphasis on standardized tests, including the ACS full year Organic exam. In light of this endorsement, it appears very worthwhile to consider the source of this dramatic drop in performance and understanding (as measured by class exam averages).

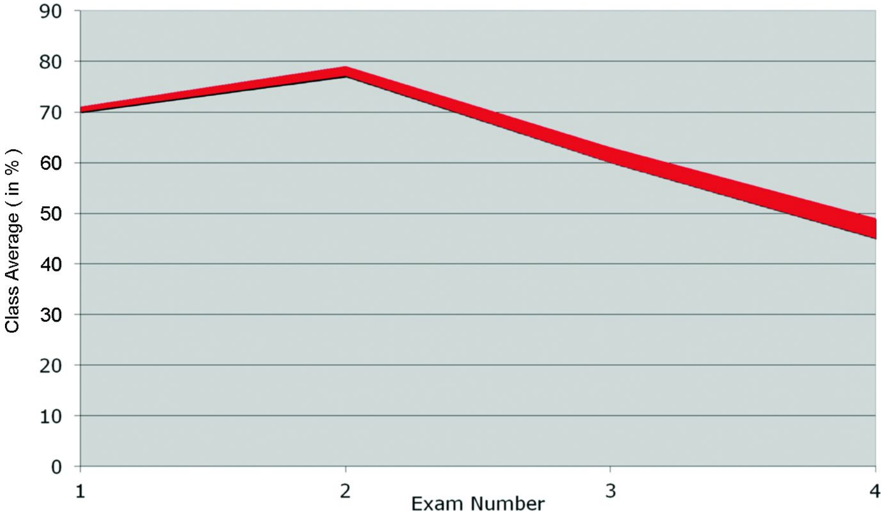


Figure 1. Typical Class Average Trend in Organic II

The Exams

Since exam averages will be used throughout this discussion, it is important to outline my exam style. My exams are a hybrid exam, with 1/3 being multiple choice questions and the remainder being short answer, fill in the missing reagents/products, synthesis, and mechanisms. There is always one extra credit question worth 9% of the total points possible on the exam. Most students easily complete these exams within the time allotted, as I attempt to write the exams for a 45 minute time period, even though the students have 55 minutes to take it.

The Source of the Problem

Why do test scores drop so precipitisely? There can be a number of possible answers to this question. One is that the instructor (myself) is just doing a poor job covering the material. In talking to other Organic professors, though, I found that they encountered similar trends in their class. So, instructor issues did not seem likely to be the answer.

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch007

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch007

The Textbook

A next idea was that it was the textbook. Over my time at Middle Tennessee State University (MTSU), we have used 3 different texts: Vollhardt and Schore Organic Chemistry 5th Edition, Solomons and Fryhle Organic Chemistry 9th Edition, and Smith Organic Chemistry 2nd and 3rd Editions (*5–7*). As can been seen in Table II, there are differences in exam performance for the different texts, although most of these differences are slight. The one possible exception is on exam 3, where both the Volhardt and Smith texts afford significantly higher class averages than the Solomons test. Still, it is worth pointing out that this difference may simply be an artifact of that one class and not a reflection of the material being clearer in the Volhardt and Smith texts. Further, attributing the difference to the textbook assumes that the students carefully read and use the textbook, which may or may not be the case.

Table II. Class Exam Averages by Textbook

Exam	*Solomons*	*Volhardt*	*Smith*
1	65%	69%	70%
2	82%	75%	77%
3	46%	56%	60%
4	50%	49%	43%

Number of Reactions

Another thought was that maybe the number of reactions in each given section was the problem. Students very often complain about how there are so many reactions and that they cannot possibly remember (memorize) them all. Using the current (3rd) edition of Smith's text, the number of reactions were determined (Table III). The reason that there are two columns for number of reactions is that student and professor determinations of what makes a reaction "different" are not the same. For example, a student would likely consider the Claisen and Dieckmann condensations to be two different reactions even though both are the condensation of two esters, with the only difference being inter- versus intramolecularity. Indeed, the reason for the large difference in the carbonyl substitution/elimination section is because I view the conversion of either an acid chloride or an acid anhydride into an ester or an amide as fundamnentally the same reaction, whereas from the student perspective, they are all different.

Table III. Number of Reactions per Exam

Exam	*# of Reactions (Professor)*	*# of Reactions (Student)*	*Average*
1	4	7	70%
2	9	11	77%
3	10/19	61	60%
4	6	18	43%

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch007

Even with this difference in opinion as to the exact number of reactions, it is clear that the number of reactions does not consistently track with class exam average, as by this figuring, exam averages on aldol chemistry should be comparable to that of aromatic chemistry.

Timing

Another possible reason that has been considered is that of timing. Carbonyl chemistry is near the end of the second semester of a challenging two semester course sequence. By that point in time, it may be that most students are simply worn out and incapable of putting forth their best effort on the material. In that case, moving carbonyl chemistry to earlier in the second semester by flipping it and the radical, dienes, and aromatic chapters should result in an improvement in performance on the carbonyl exams. It would also be expected that performance on the radical, diene and aromatics exams would suffer. To test this idea, the carbonyl chapters were moved to the start of the semester in Organic II in spring of 2011. Operationally, this is not difficult as there is very little use of radical, diene, and aromatic chemistry in the carbonyl chapters and what little that does appear, such as Friedel-Crafts acylation for the synthesis of aromatic ketones, was covered as it occurred. The results of this experiment can be seen in Table IV. The comparison is of the class taught in spring of 2011 (revised order) with spring of 2010 (standard order). The class sizes were similar (roughly 100 students in both cases), had the same instructor, and used similar (though not identical) exams.

In examining the results, there is a definite difference. Class averages on the two carbonyl exams (exams 3 and 4 in the normal order and 1 and 2 in the carbonyls first order) increase modestly, while the average on the aromatics exam does decrease slightly (exam 2 in the normal order and exam 4 in the carbonyls first order). Interestingly, the average on the radicals/dienes exam (exam 1 in the normal order and exam 3 in the carbonyls first order) actually increases significantly in the carbonyl first approach. As a result, order (and thus fatigue) is clearly not the only issue driving student performance.

Table IV. Effect of Topic Order

Exam	*Normal Order*	*Carbonyls First*	*Exam*
1 (dienes, radicals)	70%	66%	1 (carbonyl additions/substitutions)
2 (aromatics)	77%	54%	2 (aldols)
3 (carbonyl additions/substitutions)	60%	85%	3 (dienes, radicals)
4 (aldols)	43%	68%	4 (aromatics)

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch007

Number of Mechanisms

Upon further reflection, one other possible source of the problem that students have with carbonyl chemistry might be the number of reaction mechanisms. Even though students say that there are too many reactions, in fact, students often do not differentiate between reactions and reaction mechanisms. At the same time, it is well established that students struggle with arrow formalism (*8*, *9*). As seen in Table V, there are far more mechanisms in the carbonyl sections than in the radicals, dienes and aromatic ones.

Table V. Mechanism Analysis

Section	*Number of Mehanisms*
Radicals	2
Dienes	2
Aromatics	1
Carbonyl Addition/Substitution	9
Carbonyl Condensation (Aldol)	9

Although this is a plausible hypothesis, it is one that cannot be readily tested. Arrow formalism is an intrinsic part of Organic Chemistry and to teach a class without "mechanisms" would be doing the students a serious disservice. Still, this possibility might serve to focus more attention on how to more effectively teach the idea of mechanism in Organic I and II.

Conclusions

In summary, carbonyl chemistry is a very important topic in the standard Organic Chemistry sequence. It is considerably more challenging to many students and yet is of vital importance to their future success in more advanced courses as well as standardized tests. Several potential reasons for student difficulty were explored, with none adequately rationalizing the problem.

Acknowledgments

I would like to thank Rachael Hall for assisting in the student determination of number of reactions.

Downloaded by UNIV OF ARIZONA on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch007

References

1. Katz, M. Teaching Organic Chemistry via Student-Directed Learning. *J. Chem. Educ.* **1996**, *73*, 440–445.
2. Karty, J. M.; Gooch, G.; Bowman, B. G. Teaching a Modified Hendrickson, Cram, and Hammond Curriculum in Organic Chemistry. *J. Chem. Educ.* **2007**, *84*, 1209–1216.
3. Wheeler, D. M. S.; Wheeler, M. M. The Undergraduate Curriculum in Organic Chemistry. *J. Chem. Educ.* **1979**, *56*, 462–464.
4. HHMI. *Scientific Foundations for Future Physicians*; Report of the AAMC-HHMI Committee, 2009.
5. Vollhardt, P.; Schore, N. *Organic Chemistry: Structure and Function*, 5th ed.; W.H. Freeman and Company: New York, 2005.
6. Solomons, T. W. G.; Fryhle, C. B. *Organic Chemisry*, 9th ed.; John Wily & Sons: Hoboken, 2007.
7. Smith, J. G. *Organic Chemistry*, 3rd ed.; McGraw-Hill: New York, 2011.
8. Bhattacharyya, G.; Bodner, G. M. 'It Gets Me to the Product': How Students Propose Organic Mechanisms. *J. Chem. Educ.* **2005**, *82*, 1402–4107.
9. Penn, J. H.; Al-Shammari, A. G. Teaching Reaction Mechanisms Using the Curved Arrow Neglect (CAN) Method. *J. Chem. Educ.* **2008**, *85*, 1291–1295.

Chapter 8

Predictability of Organic Chemistry Students' Final Course Grades Using Four-Week Averages

J. T. Wasacz,[1,*] K. A. O. Pacheco,[2] and J. O. Schreck[2]

[1]Division of Natural Science, Mount Saint Mary College, Newburgh, NY 12550
[2]Department of Chemistry and Biochemistry, University of Northern Colorado, Greeley, CO 80639
[*]jodie.wasacz@msmc.edu

Many organic chemistry instructors believe an organic chemistry student's course grade can be predicted early in the semester of taking the course. In a recent study, first semester organic chemistry students' grades were analyzed after four weeks of the course and at the end of the semester. It was observed, upon taking the average of the first four weekly quiz grades, that there was a strong correlation with the students' final grades. Analysis showed the average grade of 47% of the students after the fourth week of the semester remained relatively unchanged by the semester's end. Of the remaining students whose grades did change, 37% of those decreased in letter grade, and only 16% improved their letter grades from the fourth week through the final.

Often instructors reach a point early in the semester where they believe they can assess their students and predict course grades for the end of the semester. However, there is little research done investigating these claims in organic chemistry. Additionally, when speaking with professors in various disciplines, it seems apparent that this theory is common across a campus. However, the question remains as to the validity in these claims. If these claims are true, and students' course grades are predictable early in the semester, then there must

In Advances in Teaching Organic Chemistry; Duffy-Matzner, J., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2012.

be certain factors that contribute to students' success in a course. Identifying these factors could prove beneficial to improving overall student success. It is, therefore, crucial to determine the validity and statistical significance in the anecdotal claims that student course grades are predictable early during the course in question.

Students experience different levels of success in a course when the typical grading scale measuring the relative level of success in a course is used. Given these varying levels, there must be factors contributing to student success that may explain why the students receive the course grade assigned to them. What factors influence student success?

A potential factor influencing success may be motivation, either intrinsic (the student's natural desire to want to learn and understand) or extrinsic (letter grade or program acceptance). Motivational factors affect student success in a course (*1*) and therefore, additional factors such as preconceptions may affect student motivation. These additional factors are crucial to investigate how to help students improve their grades early in a course. In research studies, it was discovered that the expectation of success appears to be related to an individual's behavioral choice. The expectation individuals have that they will successfully complete a task is a main factor in whether or not they even attempt the task. Attempting the task is based on students' personal beliefs about how they will perform in the task. If students feel they will have little to no success, then they will be less likely to even attempt the task. Therefore, individuals tend to choose tasks they expect to perform well on and achieve great success (*2–5*). This does not completely answer the question of what contributes to student success. The question then becomes what causes students to believe they can successfully complete a task.

To tie into student motivation, it is important to understand what variables affect student engagement. What promotes student engagement in course material? What factors allow students to be engaged for long periods of time rather than just short term? What factors influence intrinsic student motivation? To address the study, one must first look at student class attendance. For students to be motivated, they must first attend their classes and become engaged in those classes. In college courses, however, attendance is a problem for some students. Their attendance may be based solely on how they feel about the class and whether they feel their attendance is necessary. Students, who feel their attendance in a class is necessary and feel that by attending class they will get something out of it, may be more likely to attend class and have a positive attitude towards the class. These attitudes were seen to be a direct result of students' previous experiences and preconceptions (*6*). Students who are motivated are more likely to attend class. Previous studies have determined that student attitudes correlate with attendance, and student attendance is correlated to success in the course (*7–13*). Therefore, research has indicated that preconceptions must be addressed if, for no other reason, than to help form positive student attitudes contributing to student success.

To determine the validity claiming students' grades are predictable early in the semester, this research used collected data from the organic chemistry classes at the University of Northern Colorado. Organic chemistry was chosen as it is the researcher's primary field of interest and was the course taught by the researcher allowing for easy access to students' grades. At the University of Northern Colorado, organic chemistry is taught every semester; however, for the purposes of this study, only the grades of the "traditional" students, those taking organic chemistry during the fall semester, were utilized. During the fall semester, there were two sections of organic chemistry offered each having a different professor, however, both used the same text, *Organic Chemistry* by Francis Carey and Robert Giuliano, gave essentially the same exams during the course, and gave the same final exam (only weekly quizzes were different). There was no noticeable difference between the two classes; therefore, both sections were pooled together into one population.

For this study, student organic chemistry quiz grades were obtained after one-month into the semester, as well as, the final sixteen-week course grades. Grades were collected over a five-year span during the fall semester only for years 2004 - 2008. Statistical analyses were done on the grades to determine if student final grades are predictable early in the semester. Descriptive statistics were done, in addition to the determination of a correlation coefficient, to determine the predictive validity.

The research results were very promising (and not surprising to long term organic chemistry instructors). The population used for this research after combining both organic chemistry sections together was 486 students. The grading scale used for this study was based on the traditional four point scale, omitting the plus and minus distinctions. For consistency each four-week quiz average was given the corresponding grade on the 4.0 scale. Grade changes from four-weeks to the final were noted and were the basis of all analyses. Upon initial analysis of the organic students' four-week quiz average (< 10% of total grade) compared to their course grades, there were some interesting findings (Figure 1).

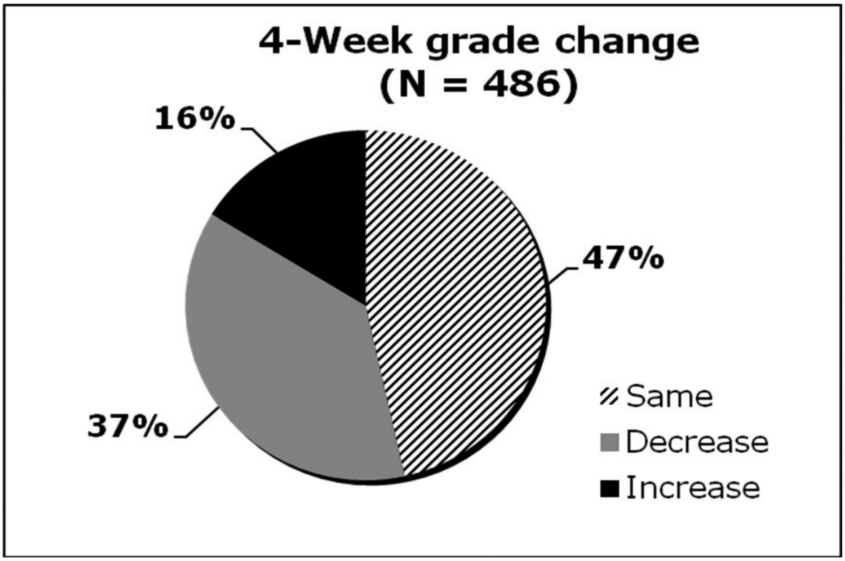


Figure 1. Representation of the changes in student grades from week four to the final course grade.

First, it was observed that a large percentage of students (47%) received the same course grade as their four-week quiz average. This means students with an "A" four-week quiz average also received a course grade of "A". The second largest percentage (37%) of students decreased their grades from week four to the course grade, and only a very small percent (16%) were able to improve their grade throughout the semester.

Based on this finding, it appears the majority of students reached their maximum grade before or at only four weeks into the course, with a little more than half staying the same, and a little less than half decreasing their performance as the semester proceeds.

This result was not surprising when considering the course material. The initial weeks, of a typical organic chemistry course, involve reviewing concepts learned in general chemistry; then introducing fundamental organic functional group families and reactions. The difficulty of the material increases as further functional groups, reactions, and mechanistic studies are introduced. However, when considering student comments during prior teaching experiences, they are under the impression they will be able to improve their grade by working hard and increasing the amount of study time committed to organic chemistry during the semester. This research does not support that idea as only a small percentage of students accomplished this feat. After this initial investigation, it was further decided to determine which students were improving their grades. The results of this analysis are shown in Figure 2.

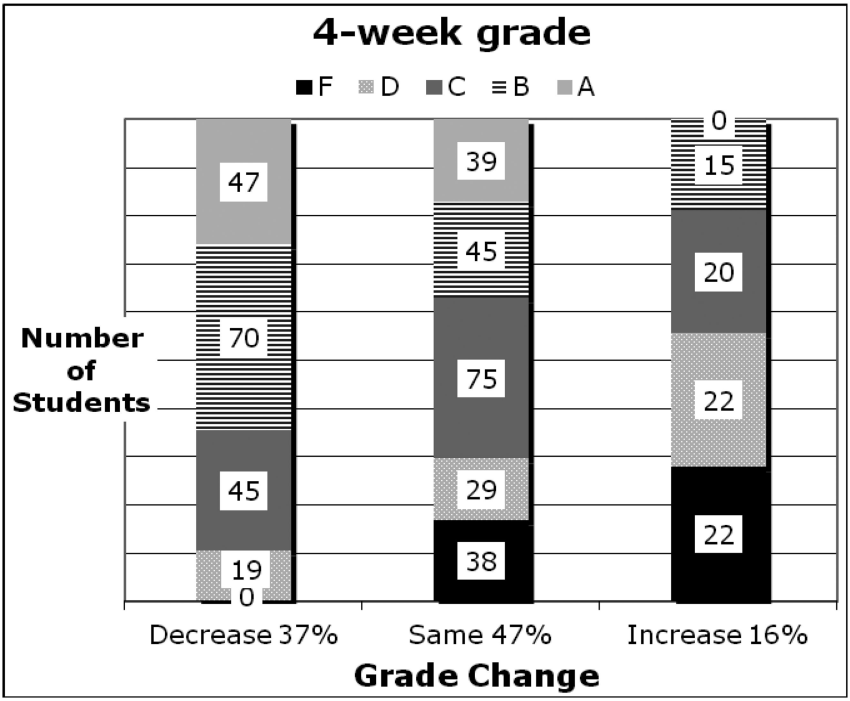


Figure 2. Distribution of the demographics of students grade changes.

Students on the lower end of the grading scale (those with a grade of D or F improving) may have different implications than students on the higher end of the grading scale (those with a grade of C or B improving). Upon investigation of these trends, it was observed the majority of students on the higher end (A and B) of the scale (117 out of a total of 181 students) decreased their grade from four weeks into the semester to the end of the semester. The majority of students on the lower end (D and F) of the scale (44 out of a total of 79 students) improved their grades during the semester. Lastly, students who earned the same grade both at four weeks and the final (149 out of a total of 226 students) consisted mainly of those in the middle of the grading scale (B, C, and D). This trend appears to show a regression towards the mean. The students on the high end mainly decrease, those on the low end mainly increase, and those in the middle stay constant.

During the first year of the study, students who received the same four-week and course grade comprised the largest percentage; however, at the end of the study, students whose grades decreased from four-weeks to their course grade comprised the largest percentage. During the course of this study, the percentage of students who were able to successfully improve their grade during the course of the semester was seen to diminish. Figure 3 shows the distribution of students from 2004 – 2008 who increased, decreased or stayed the same as their grade at the four-week point. It was observed that over the course of this study, the number of students increasing their grade appeared to decrease significantly. It was the researchers observations that the quality of students attending college seemed to be decreasing; students who are less academically motivated and students with lower academic aptitude seem to compose more and more of the majority of the class each year. In addition the intrinsic motivation of the students appears to have diminished. This trend will be further investigated in future research, but was hypothesized to be a result of the changing student dynamics and demographics.

Lastly, statistical analysis was done using the SPSS software package. A basic correlation coefficient was determined to establish predictive validity with regard to student course grades early in the semester. A perfect correlation would be a value of 1.0, and will only occur if the two variables being correlated are the same variable. For the purposes of this research, correlation coefficients are considered strong (≥ 0.6), moderate (0.4 – 0.6), weak (0.2 – 0.4), or very weak (≤ 0.2). Upon analysis, the correlation coefficient for students' four-week quiz average with their course grades was determined to be 0.741 ($\rho < 0.01$). These results support the anecdotal findings that students' course grades in organic chemistry are predictable only four weeks into the semester. A correlation coefficient of 0.714 at the given significance level ($\rho < 0.01$) adds validity to these findings.

In addition to validating the predictability of student grades, the additional presented statistics add further depth to the study in identifying what the changes are (increase, decrease, stay the same) and what type of students (A-F) are improving their course grade. Having an awareness of this information may help instructors create intervention techniques to help students improve their performance if the student is willing to put forth the effort to use these techniques. In addition, this research initiates further questions such as why, or what, is causing the regression towards the mean and why are students unable to improve their grades during the semester? These questions are the basis to further investigation of factors that may contribute to the student's success, or unfortunately, lack of success.

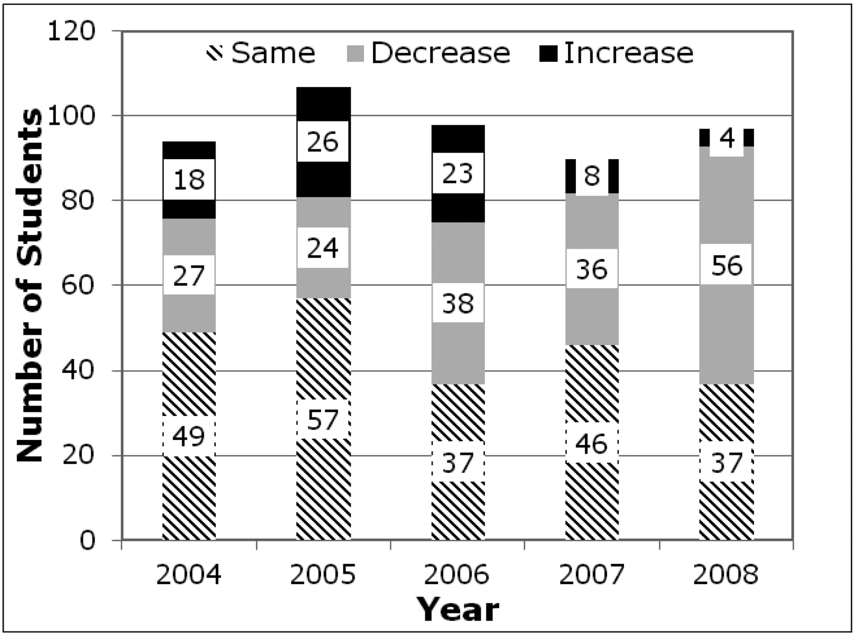


Figure 3. Student grade distribution as seen over the five years of the study.

In conclusion, this study shows that student performance early in the semester of an organic chemistry course is highly indicative of the majority of students' maximum potential performance over the entire semester. Students who were able to change their grade in a positive manner are, without question, the small minority. Interventions to assist students should be developed and implemented early in the semester to have a positive effect on student learning, and ultimately their grade.

References

1. Atkinson, J. *An introduction to motivation*; Van Nostrand: Princeton, NJ, 1964.
2. Edwards, W. The theory of decision making. *Psychological Bulletin* **1954**, *51*, 380–417.
3. Feather, N. T. Subjective probability and decision under uncertainty. *Psychological Review* **1959**, *66*, 150–164.
4. Kulka, A. *An attributional theory of choice*; Academic Press: New York, 1978; Vol. 2.
5. Parson, J. E. *Expectancies, values, and academic behaviors*; W.H. Freeman: San Francisco, 1983.

6. Gump, S. E. Guess who's (not) coming to class: Student attitudes as indicators of attendance. *Educational Studies* **2006**, *32* (1), 39–46.
7. Van Blerdom, M. L. Class attendance in undergraduate courses. .*Journal of psychology* **1992**, *126* (5), 487–494.
8. Wyatt, G. Skipping class: An analysis of absenteeism among first-year college students. *Teaching Sociology* **1992**, *20* (3), 201–207.
9. Gunn, K. A correlation between attendance and grades in a first-year psychology class. *Canadian Psychology* **1993**, *34*, 201–201.
10. Launius, M. College student attendance: Attitudes and academic performance. *College Student Journal* **1997**, *31*, 86–92.
11. Friedman, P.; Rodriguez, F.; McComb, J. Why students do and do not attend classes: Myths and realities. *College Teaching* **2001**, *49* (4), 124–133.
12. Clump, M.; Bauer, H.; Alex, W. To attend or not to attend: Is that a good question? *Journal of Instructional Psychology* **2003**, *30* (3), 220–225.
13. Gump, S. The cost of cutting class: Attendance as a predictor of success. *College Teaching* **2005**, *53* (1), 21–26.

Chapter 9

Historical Examples Integrated into the Organic Chemistry Curriculum

Kevin M. Bucholtz[*]

Department of Chemistry, Mercer University, 1400 Coleman Avenue,
Macon, GA 31207
[*]bucholtz_km@mercer.edu

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

Undergraduate organic chemistry is a challenging course for many students. The incorporation of historical examples into the curriculum provides students with a different perspective and better understanding and appreciation of the subject matter. By utilizing supplemental readings, primary literature examples, researcher profiles, and chemical history resources, the traditional curriculum in organic chemistry can be enhanced. This provides students with both the necessary content and a fuller view of organic chemistry as a discipline.

Introduction

Organic chemistry, like many other sciences, is based upon experiments, principles and theories that are derived from years of scientific discovery. Behind the science are individuals who dedicate themselves with rigorous training, long hours in the laboratory, and tedious experiments to unravel mysteries and probe interesting questions to better understanding of their surrounding world. It is the stories of the researchers, their successes, their struggles, the surprise of serendipity, and the impact of their discoveries that can provide an interesting and entertaining perspective. Organic chemistry is a content driven course, often the history and discovery is easily forgotten in a classroom setting in favor of covering greater breadth of topics, introducing advanced ideas, and maintaining the rigor that is appropriate for the discipline. Although it is important to maintain these goals, the history and impact of discoveries can help to contextualize material and provide a unique learning environment for students in the sciences.

In Advances in Teaching Organic Chemistry; Duffy-Matzner, J., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2012.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

For undergraduate students, organic chemistry is widely regarded as one of the most challenging college courses. While some students struggle to grasp the non-quantitative nature or find the volume of material to be overwhelming, others thrive in the environment and seek a greater understanding of the course content and immerse themselves in the subject. These students see the beauty, creativity, and relevancy of organic chemistry that ultimately lead the course instructor to pursue a degree in the field. Unfortunately, without making a deliberate effort, it is easy to have a disconnection between the material and the broader scope and impact of the subject. For many students, providing the context and the connection can be the key to allow for a deeper appreciation and immersion into the subject.

To allow for context for some of these approaches, Mercer University is a comprehensive institution with over 8,000 students, though the traditional undergraduate enrollment is approximately 2,200 students. The undergraduate student population spans five colleges, and these students enroll in both discipline related and general education courses within the College of Liberal Arts. Each academic year, approximately 200 undergraduates enroll in Organic Chemistry I after successful completion of General Chemistry I and II as part of an undergraduate degree program or as a requirement for entrance into the health professions. As a department, we offer seven sections of Organic Chemistry I with an enrollment of 27 in each section. Faculty typically teach two to three sections simultaneously in the lecture component and then have individual laboratory sections of 27 students. Although most of the examples in this chapter that have been implemented into the curriculum involve between 50-75 students, many of these approaches could be easily implemented into smaller classes sizes, and also could be amenable for faculty in larger class room settings to interact with students on a more personal level.

Many institutions of higher education clearly and deliberately aim to provide their students with a “liberal arts education” and actively develop “liberally educated” minds. At the heart of these ideals is a philosophy of delivering an educational experience that presents students with broad knowledge and an understanding of the world while encouraging an appreciation of how their values, ethics, and beliefs relate to these goals. In the case of organic chemistry, many enrolled students are not necessarily taking the course for the sheer enjoyment of the material or to expand their broader understanding of the world, but rather to fulfill a requirement – to pay their “dues”. Ideally, students can be exposed to this science and the history of organic chemistry to develop a well-rounded understanding and appreciation for the subject matter.

This chapter introduces and discusses several approaches and implications of incorporating historical examples into a traditional, rigorous undergraduate organic chemistry curriculum. It is designed to provide ideas and resources for academics interested in incorporating relevant historical examples into the organic chemistry classroom, focusing on approaches to implement more dynamic and thought provoking examples and pedagogy in teaching organic chemistry by integrating historical examples into the curriculum. Textbook approaches, pedagogical approaches, primary literature, profiles of individual researchers, stand-alone chemical history books, and other resources are highlighted throughout the chapter. When addressing a field as broad as chemical history,

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

it is impossible to cover every example or iteration of a case study that could possibly be incorporated by the instructor. By introducing and highlighting just a few of many of the interesting examples that can be incorporated into the organic chemistry curriculum without sacrificing the rigor and depth that is needed for the course, hopefully this will provide insight into how these examples can be implemented and integrated into the curriculum. This work is intended to inspire and provoke thought into how one might incorporate the events, people, and works into a pedagogical approach and provide students with a broader picture in their course work and curriculum.

Textbooks

Organic chemistry textbooks have evolved greatly over the last 40 years, making substantial changes in their format, use of images, colors, and integrated examples. A traditional organic chemistry textbook in the 1970's was typically black, white, and one other color, and routinely had very few illustrations or pictures to support the text. Content not easily represented in a basic typeset was difficult to integrate into the book.

A classic traditional undergraduate textbook is Morrison and Boyd's Organic Chemistry 3rd Edition (*1*). It is an extremely thorough and rigorous textbook that saw wide use at many institutions. The content, problems, and examples are challenging and introduce a number of topics at a high level. Though not the goal of the text, it contains very little historical context to many of the seminal discoveries that are discussed. For example, when introducing orbital symmetry, the book discusses the key scientists and begins to discuss the discoveries that ultimately led to the Woodward-Hoffman rules. The passage reveals that there are probably interesting and inspiring stories behind this discovery that leave readers with a well-rounded appreciation for science and a yearning for more:

> "A number of people took part in the development of this concept: K. Fukui in Japan, H. C. Longuet-Higgins in England. But organic chemists became aware of the power of the this approach chiefly through a series of papers published in 1965 by R. B. Woodward and Roald Hoffmann working at Harvard University. Very often in organic chemistry, theory lags behind experiment; many facts are accumulated, and a theory is proposed to account for them. This is a perfectly respectable process and extremely valuable. ...Woodward and Hoffmann made *predictions*, which have since been borne out by experiment. All this is the more convincing because these predictions were of the kind called "risky": that is the events predicted seemed unlikely on any grounds other than the theory being tested."

Moving forward to the present day, and current organic textbooks are filled with vivid images, shorter sections of written material, pictorial explanations of organic mechanisms, and include supplemental material such as online homework, videos, and study guides. Today's texts also include many side bars

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

and addendums that address topic such as application of material, historical scientific biographies, and introduction of advanced topics. For the most part, the topics and overarching themes have remained the same over the years, it seems as though in an effort to provide students with real world examples, additional details have been examined. Technology has allowed for textbook authors to incorporate many different components into their books, with the advantage of reaching a wider range of students with different learning skills.

A modern textbook like Vollhardt and Schore's Organic Chemistry 6th edition (*2*) has integrated "Chemical Highlights" as well as entire chapter sections that aim to make connections with historical anecdotes, societal impacts and medical relevance to the standard organic chemistry material. For example, one of the "Chemical Highlights" examines chlorination, Chloral, DDT and their dramatic environmental impacts albeit their remarkable efficacy in controlling malaria. Paul Mueller and his Nobel Prize winning work in understanding insecticidal properties of molecules is also discussed. An example like this provides students with a broader perspective into organic chemistry and illustrates both the historical context and social implication of the subject.

Napoleon's Buttons: A Supplemental Reading for Organic Chemistry

For some students, organic chemistry can be a detached subject, seemingly unrelated to any courses they have seen in their college careers. As discussed above, textbooks try to provide interesting interdisciplinary examples. Although this helps, students still struggle to make the connections not only between the real world and organic, but also science in general. To develop a more contextual learning experience in organic chemistry, the book *Napoleon's Buttons,* by Penny Le Couteur and Jay Burreson (*3*, *4*) has been introduced as supplemental reading to the required texts for the Organic Chemistry I and II at Mercer University (*5*). *Napoleon's Buttons* examines 17 molecules or classes of molecules that have had significant impacts on history, society, and culture (Table 1).

Samet and Higgins described the use of the *Napoleon's Buttons* in teaching non-major science classes at Dickinson College (*6*), but there have been no reports of this book being used in a two-semester organic chemistry course. Similarly, there have also been reports of incorporating individual historical examples into organic chemistry (*7*), but no single source exists that encompasses both semesters of the course and complements the traditional organic textbook.

To incorporate *Napoleon's Buttons* into the organic chemistry curriculum at Mercer University, the molecules (or chapters) have been integrated into the course curriculum to provide students with a novel perspective and tangible "real life" examples that supplement the corresponding chapter or topic in the organic chemistry textbook. Each chapter in *Napoleon's Buttons* focuses on one molecule, or closely related molecules, and details the affect that each one had on history. After closely examining *Napoleon's Buttons*, molecules and topics

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

from every chapter were identified that could be addressed in a typical two semester organic chemistry lecture curriculum. The *Napoleon's Buttons* chapters were then integrated into the standard sequence of an organic curriculum as supplemental reading to contextualize the textbook material. The supplementary reading provides an opportunity for students to see the interdisciplinary nature of science, the impact and relevance of organic chemistry, and the importance of a well-rounded liberal arts education.

The chapters of *Napoleon's Buttons* are written in a manner that makes it very easy for students to read each chapter independently so it is not necessary to read the book in a linear approach. This approach has been utilized with both Vollhardt and Schore's Organic Chemistry 6th ed. and Wade's Organic Chemistry 7th ed. The majority of organic chemistry books present material in a functional-group-based approach, so *Napoleon's Buttons* can be used to supplement a wide variety of textbooks independent of the order of the material covered. *Napoleon's Buttons* is also accessible to students who are not enrolled in my sections both semesters. A general approach of topics covered in the first semester is provided along with the material from *Napoleon's Buttons* in Table 2. The corresponding second semester is illustrated in Table 3.

Table 1. *Napoleon's Buttons* Chapters

Chapter	*Title*	*Chapter*	*Title*
	Introduction	9	Dyes
1	Pepper, Nutmeg, and Cloves	10	Wonder Drugs
2	Ascorbic Acid	11	The Pill
3	Glucose	12	Molecules of Witchcraft
4	Cellulose	13	Morphine, Nicotine, and Caffeine
5	Nitro Compounds	14	Oleic Acid
6	Silk and Nylon	15	Salt
7	Phenol	16	Chlorocarbon Compounds
8	Isoprene	17	Molecules Versus Malaria

Table 2. **First Semester of Organic Chemistry and Concepts Covered in *Napoleon's Buttons***

Organic Topic	***Napoleon's Buttons***	
	Ch. #	***Chapter***
Structure and Bonding		Introduction
Acids and Bases	15	Salt
Alkanes / Free Radical Halogenation	16	Chlorocarbon Compounds
Cycloalkanes	11	The Pill
Stereochemistry	17	Molecules Versus Malaria
Reactions of Haloalkanes	N/A	N/A
Preparation of Alcohols	3	Glucose
Reaction of Alcohols	4	Cellulose
Preparation of Alkenes	8	Isoprene
Reaction of Alkenes	1	Peppers, Nutmeg and Cloves
Alkynes	N/A	N/A

Typically, a chapter in *Napoleon's Buttons* is assigned to correspond with the topic currently being covered in the organic curriculum. During lectures, in-class discussions focus on the supplemental reading components that are most relevant to the current organic chemistry topic. The information in *Napoleon's Buttons* is used in a variety of formats. It can be used to preview a subject, discussed at the end of a topic as a summary of the material or integrated as a specific example or problem.

For example, in-class discussions of Chapter 1 – Pepper, Nutmeg, and Cloves examined how Spain looked to expand its control on the spice trade. Christopher Columbus set sail to find a shorter route to India and accidentally discovered the West Indies. Although he was unable to find a source of pepper, he was able to bring the chili pepper back after his second voyage. This allows for a transition into a discussion of capsaicin and piperine. Other molecules, like eugenol from cloves, isoeugenol from nutmeg, and zingerone from ginger are responsible for the hot or spicy flavors in those spices. These three molecules are structurally similar but have very different smells and flavors. This provides opportunities to discuss the difference in constitutional and geometric isomers in alkenes in the first semester of undergraduate organic chemistry.

A second example is Chapter 9 – Dyes, which covers the process in which cotton is dyed with a compound called indigo to produce blue jeans and denim. Plants that produce the indigo molecule do not have the characteristic blue color. It is not until fermentation in alkaline conditions and subsequent oxidation that the color is present. Indigo and the other dyes introduced in the chapter illustrate much of the material covered when examining conjugated alkene systems, ultraviolet spectroscopy and ultraviolet activity.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

Table 3. Second Semester of Organic Chemistry and Concepts Covered in *Napoleon's Buttons*

Organic Topic	***Napoleon's Buttons***	
	***Ch.* #**	***Title***
Spectroscopy (NMR / IR / MS)	2	Ascorbic Acid
Conjugated Pi-Systems	9	Dyes
Aromaticity / Electrophilic Aromatic Substitution	5	Nitro Compounds
Ketones / Aldehydes	N/A	N/A
Carboxylic Acids	14	Oleic Acid
Carboxylic Acid Derivatives	10	Wonder Drugs
Enolates and Condensations	12	Molecules of Witchcraft
Amines	13	Morphine, Nicotine, and Caffeine
Phenols	7	Phenol
Biochemistry	6	Silk and Nylon

A final example is Chapter 10 – Wonder Drugs, which illustrates how willow trees are a natural source of salicylic acid. Salicylic acid was the natural product Hippocrates used to reduce fevers and relieve pain. In one transformation, salicylic acid can be converted to acetyl salicylic acid, more commonly known as aspirin. The development of aspirin is a great example to focus on pKa values, properties of carboxylic acids and derivatives, and their corresponding reactivities.

Not only was the incorporation of *Napoleon's Buttons* a nice break in the lecture for the organic students, it also provided the opportunity to provide relevant examples, to see the context, and ultimately, to make the material more interesting and enjoyable. The students also learned that many significant scientific discoveries have been made through a mixture of hard work and serendipity. Based upon formal student feedback, the students read the majority of the book when they knew that questions about the readings would be on quizzes and exams. They also felt that lectures that discussed the material were successful learning experiences. They overwhelmingly reported that the book allowed them to have a better understanding and connect the course material on a higher level. The most encouraging piece of data from the surveys came in response to a question addressing the future use of the book. Students' free responses provided candid insight about how they felt about the book and the approach used. 84% of the student feedback in free response was positive about the approach and 56% explicitly appreciated how the material was interesting and related to topics outside of the course. Other anecdotal responses from students provide interesting perspective. One student illustrates the connection between other courses: "The chapter on sickle cell complemented not only what were discussing in this class but also in biology." Another student commented: "We

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

were taught what was supposed to be taught, plus all of the history in *Napoleon's Buttons*. I liked *Napoleon's Buttons*; I thought it was interesting and well-written, and it was nice to take a break and talk about it in class every now and then." And finally even students who showed low interest level in reading the book still enjoyed the discussions "Never read the book, but the class discussions made the course more interesting."

The use of *Napoleon's Buttons* is an effective approach to supplement the modern organic textbook. The advantage to incorporating the book into the curriculum is that students are introduced to many molecules that have had significant social, political, and historical importance and they can be discussed in context with the material being covered in the organic textbook. The book provides excellent examples of the interdisciplinary nature of science and the impact and relevance of organic chemistry, as well as many of the tenets of a well-rounded liberal arts education.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

Primary Literature

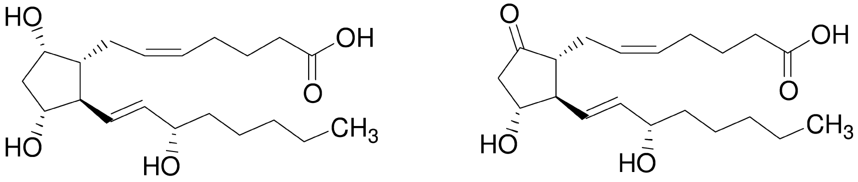
The primary literature is seldom used directly in undergraduate organic chemistry, Undergraduate textbooks do include references and for students this can cause a disconnect between the material and the actual scientific discovery. Although many papers are beyond the scope of introductory organic chemistry, there are many that provide reactions, mechanisms, syntheses and concepts that can be used effectively in the course. Besides the obvious outcome of introducing students to work directly from the primary literature, it provides students with context for many of the concepts they are learning. While the peer reviewed literature can be utilized to highlight mechanisms, spectroscopy and the rational approach of synthetic methodology, the utilization of papers concerning the total synthesis of natural products clearly demonstrates the synergy and creativity in a total synthesis. At first a student may be overwhelmed by "jumping into" syntheses from the primary literature, but with judicious selection, these papers can provide a unique teaching opportunity and aid in the development of synthesis skills.

Within the organic chemistry curriculum at Mercer University, two specific papers have been identified and implemented into the curriculum. As the class progresses through new topics in the course, students can refer to these classic syntheses where relevant reactions, compounds, and concepts are discussed. Step by step, these "daunting" reactions become clear to the students, in a manner that emphasizes connections between concepts and provides a fuller understanding of organic chemistry. Students discover their ability to grasp ideas that, at the onset, were intangible. This experience is rewarding for students and spurs their desire to learn and understand, rather than memorize as a means to an end.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

E. J. Corey's Synthesis of Two Prostaglandins

E. J. Corey and coworkers' 1969 report of the stereo-controlled synthesis of Prostaglandin F_{2a} (PGF_{2a}) (**1**) and Prostaglandin E_2 (PGE_2) (**2**) (Figure 1) is a paper that is accessible to students in a traditional Organic II course (*8*). Prostaglandins are derived from fatty acids and were first identified by von Euler in 1934 (*9*). By 1966, the first structures of prostaglandins were established (*10*). All prostaglandins have 20 carbons and include a substituted cyclopentane containing multiple stereogenic centers. The prostaglandin family has many interesting biological properties (*11*), including mediating muscular contraction and inflammation. They also play a role in calcium movement, hormone regulation, and cell growth control. Non-Steroid Anti-Inflammatory Drugs (NSAIDS) such as aspirin and ibuprofen block a step in their biosynthesis. Specifically, PGE_2 and PGF_2 are used to induce child birth.



1
$PGF_{2\alpha}$

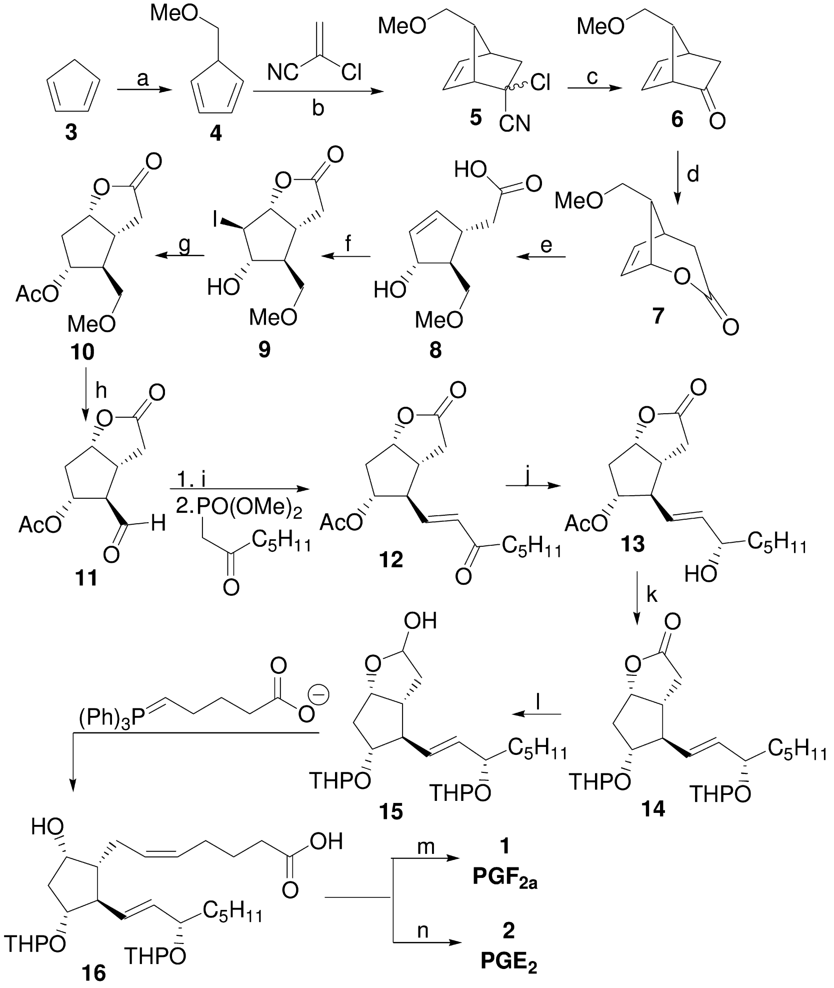
2
PGE_2

Figure 1. Structures of Prostaglandins

The Corey total synthesis reported of **1** and **2** (Scheme 1) is easily incorporated into the organic chemistry curriculum because all of the reactions are either covered in an undergraduate organic textbook or can be easily related to, based upon other reactions with which they are familiar.

The synthesis uses key reactions such as substitution (**3** to **4**), Diels-Alder (**4** to **5**), Baeyer-Villiger oxidation (**6** to **7**), iodolactonization (**8** to **9**), free radical deiodination (**9** to **10**), oxidations (**10** to **11** and **16** to **2**), reductions (**12** to **13** and **14** to **15**), protection/deprotection strategies (**9** to **10**, **13** to **14**, and **16** to **1** and **2**), and olefinations (**11** to **12** and **15** to **16**). These reactions provide opportunities to discuss retrosynthetic analysis, and the finer points of the synthesis of complex natural products. In addition, this synthesis lends itself to good conversations about stereochemistry and diastereoselectivity.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009


3
a
4
MeO
NC
Cl
b
MeO
Cl
5
CN
c
MeO
6
O
d
MeO
O
7
O
e
HO
O
HO
MeO
8
f
I
HO
MeO
9
O
O
g
AcO
MeO
10
O
O
h
AcO
H
O
11
1. i
2. PO(OMe)₂
C₅H₁₁
O
AcO
12
C₅H₁₁
O
j
AcO
13
C₅H₁₁
HO
k
O
O
THPO
14
C₅H₁₁
THPO
l
OH
O
THPO
15
C₅H₁₁
THPO
(Ph)₃P
O
O⁻
HO
OH
O
THPO
16
C₅H₁₁
THPO
m
1
PGF2a
n
2
PGE₂

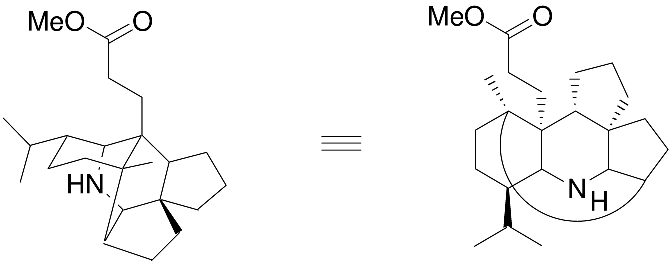
a) 1. NaH, THF; 2. $MeOCH_2Cl$,THF, -55°C b) $Cu(BF_4)_2$, 0°C c) KOH, H_2O / DMSO d) mCPBA, $NaHCO_3$,CH_2Cl_2 e) NaOH, H_2O 0°C; then CO_2 f) KI_3, $NaHCO_3$, H_2O, 0°C g) 1. Ac_2O, pyridine 2. n-Bu_3SnH, AIBN, bnz., Heat h) 1. BBr_3, CH_2Cl_2, 0°C 2. PCC, CH_2Cl_2, 0°C i) NaH, DME, 25°C j) $Zn(BH_4)_2$, DME k) 1. K_2CO_3, MeOH 2. DHP, TsOH, CH_2Cl_2 l) DIBAL-H, bnz., -60°C m) AcOH,H_2O 37°C n) 1. $H_2Cr_2O_7$, bnz. / H_2O 2. AcOH, H_2O,37°C

Scheme 1. Corey's Synthetic Route to the Prostaglandins

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

Clayton Heathcock's Synthesis of Methyl Homosecodaphniphyllate

A second paper by Clayton Heathcock and coworkers reported the synthesis (*12*) of the complex methyl homosecodaphniphyllate (**17**) (Figure 2) with its pentacyclic framework and 8 contiguous stereocenters. Compound **17**, which is isolated from the Japanese Yuzuriha tree, is one of the over 100 daphniphyllum alkaloids. For many centuries, it was used as a treatment of asthma in traditional Chinese medicine (*13*).



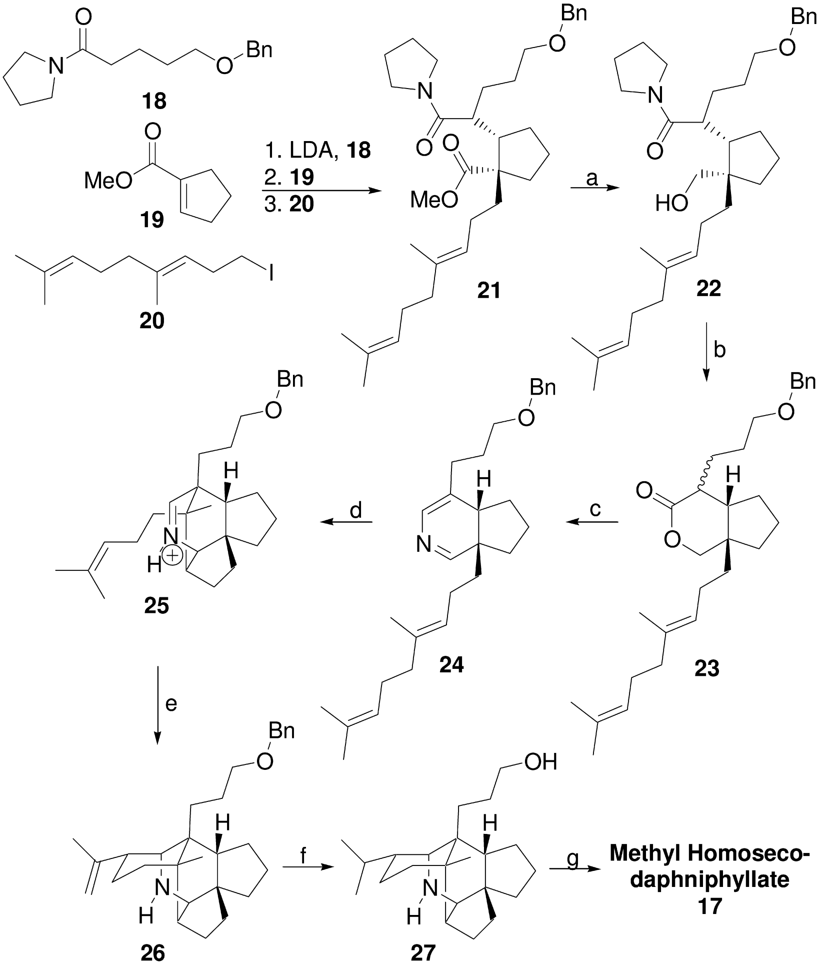
17 **17**

Figure 2. Structure of Methyl Homosecodphniphyllate

Like the prostaglandin synthesis above, Heathcock's synthesis of methyl homosecodaphniphyllate (**17**) (Scheme 2) introduces the primary literature to students, and incorporates reactions that students have become familiar with through standard coursework. Heathcock's synthesis utilizes a Michael addition followed by trapping of the resulting enolate to generate the carbon backbone (**18**, **19** and **20** to **21**). Further functional group transformation including reductions (**21** to **22** and **23** to **24**) and carboxylic acid derivative manipulations (**22** to **23**) prepare the molecule for an intramolecular heteroatom Diels Alder reaction (**24** to **25**). The resulting iminium undergoes an aza-Prins cyclization (**25** to **26**) to form the carbon skeleton. Subsequent hydrogenation (**26** to **27**), oxidation and esterification (**27** to **17**) form the complex alkaloid.

Between these two syntheses by Corey and Heathcock, a wide range of reactions and concepts are covered and can provide unique learning opportunities. Undergraduate organic students are rarely introduced to the primary literature and are not exposed to complex total synthesis in their textbooks. By adopting this approach into the curriculum, students have the opportunity to understand the approaches, strategies and elegance of a well planned synthesis.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009



a) DIBAL-H b) 1. KOH, H_2O, EtOH 95°C 2. H_3O^+ c) 1.$LiAlH_4$, THF, then H_3O^+
2. $(COCl)_2$, DMSO, Et_3N, CH_2Cl 3. NH_3 d) 1. AcOH, NH_4OAc, 25°C 2. 25° C
e) AcOH, 70°C f) H_2 / Pd, HCl g) 1. CrO_3, H_2SO_4, H_2O, Acetone 2. MeOH, H_2SO_4

Scheme 2. Heathcock's Synthetic Route to Methyl Homosecodaphniphyllate

Researcher Profiles

Organic chemists conduct research in areas ranging from physical organic, to methodology development, to total synthesis, to applied fields like bio-organic and materials chemistry. There have been many chemists that are worthy to be profiled in an organic chemistry course. Synthetic chemists like William Johnson, Robert B. Woodward, Albert Eschenmoser, Marshall Gates, Clark Still and others completed many syntheses that would help to shape and define many

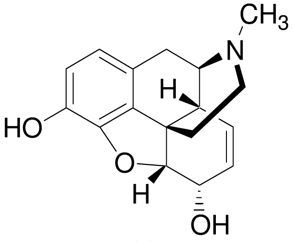
Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

aspects of organic chemistry and inspire the chemists of today. Similarly, recent developments in organometallic catalysis have greatly added to the "synthetic toolbox" possessed by chemists. Methodologies like Robert Grubbs' ruthenium catalyzed olefin metathesis are now included in many organic textbooks more regularly.

Many scientists have contributed tremendous amounts to the field of synthetic organic chemistry, and it is very hard to pick only a couple of examples to showcase. The two researchers that are highlighted, Marshall Gates and Clark Still, provide entertaining stories and give undergraduates interesting perspectives on the how research projects develop and the strength of interdisciplinary research.

Marshall Gates: The Story of the Synthesis of Morphine

An historical example that can be easily used an organic chemistry course is the story of Marshall Gates and the successful first total synthesis of morphine (**28**) (Figure 3). This example has great significance due to both morphine's powerful analgesic activity, as well as the importance of understanding the role of morphine during World War II. The pharmaceutical company Squibb developed the morphine syrette to administer morphine to wounded soldiers. The syrette, which was similar to a syringe, was pinned to the collar of the soldier to prevent overdosing. Morphine, which is obtained typically from India, was of limited supply and development of synthetic routes to the drug was very important because of its potential value in the war. In the development of its synthesis, it also reveals a story that highlights to students that what is predicted on paper as the product of a reaction is not always realized in the laboratory, and clearly demonstrates the important role that spectroscopy plays in structural elucidation.



28

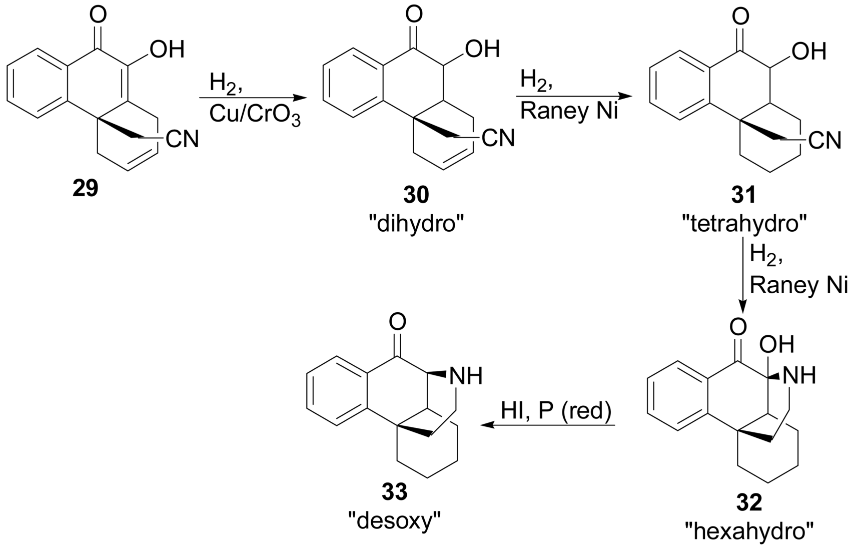
Figure 3. Structure of Morphine

In the 1940's, Marshall Gates began his academic career examining the synthesis of ring systems that are present in morphine. After several publications on the development of routes to the multiple rings of the complex alkaloid structure (*14*), the project took an unexpected turn (*15*). In the methodology to establish the ring system of morphine, a key intermediate 9,10-dioxo-13-cyanomethyl-3,8,9,10,13,14-hexahydrophenanthrene (**29**) was proposed to be converted to a "desoxy" compound (**33**) (Scheme 3). Without the

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

use of many of the instrumental techniques that students (and even many synthetic organic chemists) take for granted today, they relied upon simple chemical tests to provide qualitative analysis and help to confirm functionalities. The compounds he examined were named "dihydro", "tetrahydro", "hexahydro" and "desoxy" based upon their overall reduction from the starting parent compound (**29**). In converting the starting compound (**29**) to the "desoxy" (**33**), there was a significant inconsistency in the use of oxime formation to test for the presence of aldehydes and ketones and this made Gates and coworkers question the proposed structures. Other inconsistencies in the original proposed reaction sequence included:

1) The "dihydro" compound (**30**) fails to reduce periodic acid and yield an azine with *o*-amino-aniline.
2) The "hexahydro" (**32**) and "desoxy" (**33**) compounds have very low basicity.
3) The "dexahydro" (**32**) fails to undergo ether formation.
4) The "desoxy" (**33**) compounds fails to undergo oxime formation, be reduced by Wolff-Kischner conditions, and undergo methylation with CH_3I.
5) The "desoxy" (**33**) compound loses the oxygen completely with $LiAlH_4$.

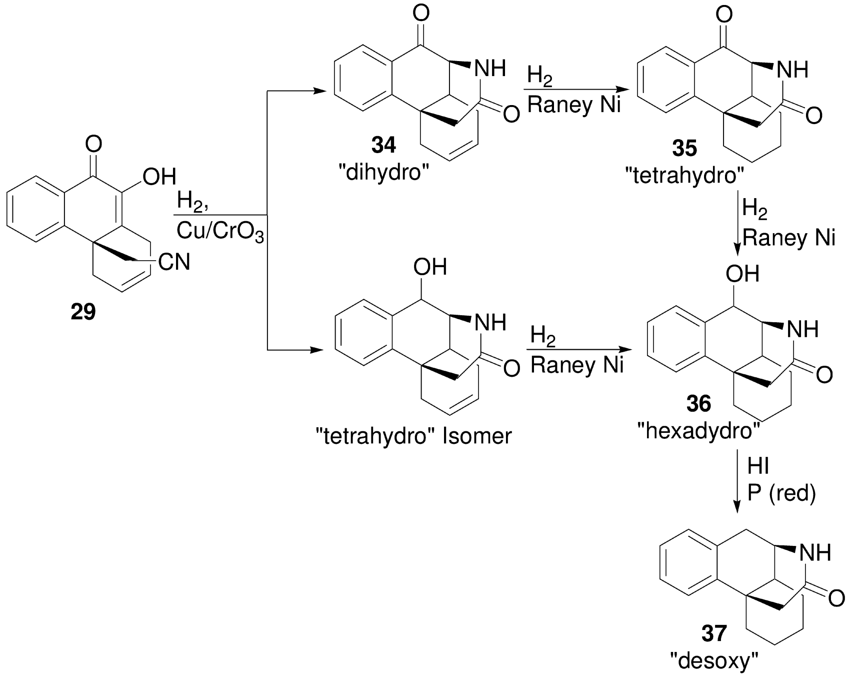


Test / Observation	30	31	32	33
Acetyl	+		+ (diacetyl)	+
Oxime	+	+		-

Scheme 3. Hydrogenation to the Proposed Desoxy Compound

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

In trying to determine what and how the product was being formed, Gates had access to new pieces of instrumentation (UV and IR) that had recently been developed. These analytical techniques made it possible to elucidate the molecule's structure. Based upon the UV and IR spectrum of the compounds from the original route, the molecules should have all contained conjugated phenone signals. But when the UV spectra were collected for each compound, the conjugation was seen in the "dihydro" and "tetrahydro" compounds, and an isolated benzene was seen in the "hexahydro" and "desoxy" compounds. The IR spectra revealed the "dihydro" and the "tetrahydro" did not have the characteristic stretch at 2100 cm^{-1} for the nitrile. All four of the compounds had a strong band for the cyclic amide and N-H absorptions. The "dihydro" and "tetrahydro" compounds did show a conjugated carbonyl. Based upon this key data coupled with the qualitative analysis, Gates and coworkers were able to identify the compounds (**34-37**) and obtain a better understanding of the molecules' reactivities. With this knowledge in hand, they were then able to finish the synthesis a few years later (Scheme 4) (*16*). Gates' synthesis of morphine was a remarkable achievement and addressed a societal and national need during the war time.



Scheme 4. Actual Conversion to the "Desoxy" Compound

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

Clark Still: A Modern Day Renaissance Chemist

Clark Still is a chemist that has significantly contributed to a wide variety of chemical disciplines ranging from methodologies, total syntheses, chromatography, computational chemistry, and chemically encoded libraries. One of his most highly cited papers addresses the best and most efficient way to run column chromatography (*17*). This particular paper is one that many undergraduates and first year graduate students read, and as of March 2012 it has been referenced over 4200 times. Still also spent time developing computational methods to conduct conformational analysis in order to examine large rings and their structures (*18*). He also developed a method for labeling solid-phase libraries with aromatic halocarbon chemical modifiers which could be identified easily on a gas chromatogram (*19*). Still's career illustrates the robust nature of multi- and inter-disciplinary research and the impact they can have.

Still is also well known for his work in the total synthesis of periplanone B (**38**) (Figure 4) (*20*). This is an elegant synthesis that highlights the power of stereochemical control and the use of large rings to control reaction selectivity. It also illustrates the importance of total synthesis to confirm and validate original proposed structures, and the inherent importance of stereochemical relationship and biological activity. Periplanone B is female cockroach pheromone that was first discovered in 1963 (*21*), and a preliminary structure without stereochemistry was identified in 1976 (*22*). Still leveraged his work on the conformational preferences of ten-membered rings to guide the synthesis. By controlling the selectivity of several key epoxidations, three of the possible four stereoisomers of periplanone B could be accessed. Because the absolute configuration of the isolated natural product was unknown the synthesized molecules could be compared to the natural sample to confirm the structure. By comparing the isolation and spectral data to the synthesized compounds and conducting bioassays, the absolute configuration was identified (*23*).

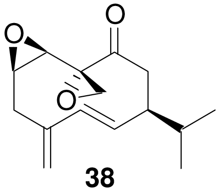

38

Figure 4. Structure of Periplanone B

The bioassays were a simple, behavioral test that illustrates the interplay between organic chemistry and other disciplines like biology, neuroscience and psychology. To assay the compounds, the isomers were individually applied to filter paper at various concentrations. The filter paper was place in a Pasteur pipette and the samples were tested by blowing an air stream across the paper into a jar containing male cockroaches. By observing the behavioral response of the cockroaches (wing fluttering and copulatory attempts) to the different isomers, the active synthetic compound was identified. This then confirmed the absolute configuration of natural periplanone-B.

Chemical History Books

There are many other books that can be used at the undergraduate level to introduce students to history of chemistry, and supplement the modern organic textbook. Some of these books have had general reader appeal while others have a more technical slant. These books are not meant to be a replacement for a standard textbook. Rather, they provide interesting examples and are a good starting point for someone interested in expanding historical examples into their course. What follows are a few texts that can be used either by organic students to support and strengthen their understanding of organic chemistry, or by organic instructors to strengthen synthesis examples in lecture.

Arthur Greenberg's *A Chemistry History Tour: Picturing Chemistry from Alchemy to Modern Molecular Science* (*24*) is an excellent source for material to supplement a traditional curriculum, or to be used a standalone book for a survey science course for non-majors, depending upon the institutional educational requirements. This book is not designed to be a work that addresses the complete development of chemistry but is meant to examine selected highlights in chemical history. It contains lots of images, pictures, and diagrams to lead readers through the topics ranging from the earliest alchemists to the development of modern day bonding theories.

A recently released book, *Letters to a Young Chemist* (*25*), is a compilation of letters written by eminent research scientists to a fictitious student interested in chemical research. Each letter addresses how and why the researcher became interested in their field of expertise. The author describes the development of their discipline, as well as their perceptions regarding the future direction of their work. The book addresses the ideas of chemistry being a central science and identifies areas where their work has and will continue to have significant impact into the well being of the human population. The letters and fields are grouped into four main categories: "Fundamentals to Application," "Chemistry and the Life Sciences," "Functional Materials," and "Chemistry and Energy."

Nicolaou and Montagnon's *Molecules that Changed the World* (*26*) is a recently released "coffee table" style book that examines 34 fascinating molecules that have long been the focus on scientists from many different disciplines. The book recounts the efforts of multiple researchers to understand and gain insight into specific molecules, and the profound influence these molecules have on society's daily lives. From an organic chemistry standpoint this work is extremely thorough and wide ranging. Additionally, each chapter provides an historical account of the compound, followed by the chemical and biological investigation into the small molecules. The approach and voice of the book looks to "tell the stories" and identify and highlight the work that was going on simultaneously in order to understand challenging problems and questions. Even though this book is geared towards a more general audience, references to the primary literature and secondary reviews are included and can be utilized as teaching resources when implementing these chapters into the curriculum.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

Chemical History and Heritage Organizations

Chemical history and heritage is a rich and diverse discipline that is a focus of two large organizations. The American Chemical Society has developed the Division of the History of Chemistry (*27*). The mission of this division is to advance knowledge and appreciation of the history of the chemical sciences among chemists, students, and historians of science and the broader public. This technical division regularly has sessions at the American Chemical Society National Meetings; for example, at the Fall 2011 National Meeting in Denver, CO, the division sponsored 33 presentations (*28*). A second organization, The Chemical Heritage Foundation works to foster an understating of chemistry's impact on society (*29*). The foundation has a library of chemical history, an outreach arm responsible for a museum, and publications including "Chemical Heritage," a center for contemporary history and policy, and a research center for visiting fellows.

More broadly, there are also specific academic programs that specialize in the History of Science and work to document and record scientific history. The History of Science Society (*30*) provides resources, databases and large bibliographies for work in this field. Along with representing the students in over 30 graduate programs in the United States, the group with over 3,000 members works to understand the historical impact of science, medicine, technology, and their interactions with society. Both of these organizations provide countless opportunities for instructors to incorporate historical examples into their lecture.

Conclusions

Undergraduate organic chemistry is a subject that is challenging for many students. By incorporating peer-reviewed literature as well as historical examples into the curriculum, students can be exposed to the impact, elegance and stories of the science and are better able to relate and appreciate the material. Integration of examples can be accomplished through multiple routes.

- Current textbooks: Often these books include in-text sections and examples to profile specific molecules and researchers.
- *Napoleon's Buttons* as a supplementary text: This book can be used as a supplementary text to the traditional undergraduate organic textbook to highlight the historical and society impacts specific molecules have had.
- Primary literature: Corey's synthesis of the prostaglandins and Heathcock's synthesis of methyl homosecodaphniphyllate introduce students to total synthesis and integrates the primary literature into the curriculum.
- Researcher Profiles: The work of Marshall Gates and Clark Still can be examined to highlight the necessity of total synthesis, the development of novel analytical techniques and their influence on other fields and to encourage multi- and inter-disciplinary research.

In Advances in Teaching Organic Chemistry; Duffy-Matzner, J., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2012.

- Chemical history books and societies: These texts and organizations provide innumerable resources to faculty for the integration of examples into the organic chemistry curriculum.

The approaches described in the chapter provide faculty with opportunities to integrate historical examples into the organic chemistry curriculum and introduces students to a perspective that is often overlooked. Incorporation of peer-reviewed literature and historical example not only benefits the student but allows for the professor to remain connected to his or her discipline.

Acknowledgments

The author would like to thank Adam Kiefer (Mercer University) for his insight and thorough review of the chapter and the fruitful discussion that resulted about undergraduate organic chemistry pedagogy. Daniel Bolt provided valuable feedback from an undergraduate student's perspective. Lastly, Robert K. Boeckman (University of Rochester) offered insight and perspective into Marshall Gates' synthesis of morphine.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

References

1. Morrison, R. T.; Boyd, R. N. *Organic Chemistry*, 3rd ed.; Allyn and Bacon, Inc.: Boston, MA; p 938.
2. Vollhardt, P.; Schore, N. *Organic Chemistry: Structure and Function*, 6th ed.; W. H. Freeman and Company: New York; p 118.
3. Le Couteur, P.; Burreson, J. *Napoleon's buttons: 17 molecules that changed history*; Penguin Group Inc.: New York, 2003.
4. Dalton, L. *Chem. Eng. News* **2003**, *81*, 42.
5. Bucholtz, K. M. *J. Chem. Educ.* **2011**, *88*, 158.
6. Samet, C.; Higgins, P. J. *J. Chem. Educ.* **2005**, *82*, 1496.
7. (a) Kurzer, F. *J. Chem. Educ.* **2000**, *77*, 851. (b) Ryan, D. P. *J. Chem. Educ.* **1977**, *54*, 638.
8. Corey, E. J.; Weinshenker, N. M.; Schaaf, T. K.; Huber, W. *J. Am. Chem. Soc.* **1969**, *91*, 5675.
9. Euler, U. S. v. *Arch. Exp. Path. Pharmakol.* **1934**, *175*, 78.
10. Bergström, S. Isolation, structure and action of the prostaglandins. In *Prostaglandins*; Bergström, S., Samuelsson, B., Eds.; Proc. 2nd Nobel Symposium, Stockholm, 1966.
11. Kadowitz, P. J.; Jainer, P. D.; Hyman, A. L. *Annu. Rev. Pharmacol.* **1975**, *15*, 285.
12. Ruggeri, R. B.; Hansen, M. M.; Heathcock, C. H. *J. Am. Chem. Soc.* **1988**, *110*, 8734.
13. Morita, H.; Kobayashi, J. Daphniphyllum alkaloids: Structures, Biogenesis, and Activities. In *Modern Alkaloids: Structure, Isolation, Synthesis and Biology*; Fattorusso, E., Taglialatela-Scafati, O., Eds.; Wiley-VCH Verlag GmbH & Co. KgaA: Weinheim, Germany, 2007; pp 541−589.

14. (a) Gates, M.; Newhall, W. F. *J. Am. Chem. Soc.* **1948**, *70*, 2261. (b) Gates, M. *J. Am. Chem. Soc.* **1950**, *72*, 228.
15. Gates, M.; Woodward, R. B.; Newhall, W. F.; Künzli, R. *J. Am. Chem. Soc.* **1950**, *72*, 1141.
16. Gates, M.; Tschudi, G. *J. Am. Chem. Soc.* **1956**, *78*, 1380.
17. Still, W. C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.
18. Mohamadi, F.; Richards, N. G. J.; Guida, W. C.; Liskamp, R.; Lipton, M.; Caufield, C.; Chang, G.; Hendrickson, T.; Still, W. C. *J. Comput. Chem.* **1990**, *11*, 440.
19. Ohlmeyer, M. H. J.; Swanson, R. N.; Dillard, L. W.; Reader, J. C.; Asouline, G.; Kobayashi, R.; Wigler, M.; Still, W. C. *Proc. Natl. Acad. Sci.* **1993**, *90*, 10922.
20. Still, W. C. *J. Am. Chem. Soc.* **1979**, *101*, 2493.
21. Jacobson, M.; Beroza, M.; Yamamoto, R. T. *Science* **1963**, *139*, 48.
22. Persoons, C. J.; Verwiel, P. E. J.; Ritter, F. J.; Talman, E.; Nooijen, P. J. F.; Nooijen, W. J. *Tetrahedron Lett.* **1976**, *17*, 2055.
23. Adams, M. A.; Nakanishi, K.; Still, W. C.; Arnold, E. V.; Clardy, J.; Persoons, C. J. *J. Am. Chem. Soc.* **1979**, *101*, 2495.
24. Greenberg, A. *A Chemical History Tour: Picturing Chemistry from Alchemy to Modern Molecular Science*; Wiley-Interscience: New York, 2000.
25. *Letters to a Young Chemist*; John Wiley and Sons, Inc.: Hoboken, NJ, 2011; pp 51−75.
26. Nicolaou, K. C.; Montagnon T. *Molecules that Changed the World*; Wiley-VCH: Weinheim, 2008.
27. American Chemical Society Division of the History of Chemistry. http://www.scs.illinois.edu/~mainzv/HIST/ (accessed Feb. 3, 2012).
28. *242nd American Chemical Society National Meeting & Exposition*: Book of Abstracts; American Chemical Society: Washington, DC, 2011; 116-TECH.
29. Chemical Heritage Foundation. http://www.chemheritage.org/ (accessed Feb. 3, 2012).
30. History of Science Society. http://www.hssonline.org/index.html (accessed Feb. 15, 2012).

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch009

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

Chapter 10

Blending Organic and General Chemistry: A Unified and Holistic Curriculum Reform Effort

David P. Cartrette*[*] and Matthew L. Miller

**Department of Chemistry & Biochemistry, South Dakota State University,
Brookings, SD 57007
[*]David.Cartrette@sdstate.edu**

Curriculum reform efforts aimed at improving chemistry education are varied in context as well as approach, but most of these efforts described in the literature are not holistic in design. This chapter describes a curriculum reform model implemented for chemistry and biochemistry majors at South Dakota State University. The objectives for the redesigned curriculum include restructuring the first two years of instruction to incorporate a blended approach, focusing on inorganic and organic chemical contexts, to teach the fundamental principles of chemistry as a discipline. The model begins with a qualitative description of atoms and molecules, and builds in quantitative rigor throughout the first two years of instruction. The accompanying laboratory curriculum is also described, in which the pedagogical approach is to train students in their first semester to use advanced instrumentation. In subsequent semesters, students begin to design and implement individual experimental procedures. The holistic approach we adopted is meant to create a spirit of community among beginning undergraduate chemistry and biochemistry majors to propel them into undergraduate research earlier in their academic training.

Introduction and Background

As the title of this book suggests, its component chapters should address issues related to improving or advancing the teaching of organic chemistry. The

In Advances in Teaching Organic Chemistry; Duffy-Matzner, J., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2012.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

use of value-laden words (advancing or improving) in the title suggests that something is inherently "wrong" with the way organic chemistry is taught at most institutions. The majority of chemistry instructors at higher education institutions would likely fall somewhere between two polarized camps when asked to respond to this statement: yes, there *are* some things wrong, or no, things are fine in the organic chemistry classroom. We also take a position somewhere in between these two camps, squarely in the middle of the no man's land of curriculum development and refinement. We find the following things "right" with the way that organic chemistry is currently taught:

- Its placement in the undergraduate curriculum is appropriate, given that more advanced courses which require an understanding of organic chemistry (e.g., biochemistry) logically follow
- It provides valuable skills for future coursework and/or careers, especially in terms of three-dimensional thinking, predicting, structure drawing, analyzing, and explaining
- Its laboratory component expands the repertoire of skills and techniques that students will need in authentic research and future laboratory courses
- Its comprehensive nature provides insight into classical reactions and their mechanisms, and allows freedom for incorporating more modern reactions described in the chemical research literature

This list is not intended to be exhaustive; there are other good things about traditional organic chemistry instruction. On the other hand, there are issues which merit further thought about the way organic chemistry is traditionally taught:

- For a class that is dedicated to the reactions of one element, it represents an enormous amount of knowledge that many instructors believe they **must** cover in the span of two semesters
- Several paradigms are stressed causing an overload in the ability of students to cope with the material presented (*e.g.*, some instructors of organic chemistry focus almost exclusively on mechanistic aspects, while others stress synthesis, while still others emphasize physical aspects of organic chemistry)
- Very different thought processes are involved in learning organic chemistry and solving problems related to it than those learned in prerequisite coursework (in most instances, general chemistry II), as well as subsequent coursework (*e.g.*, analytical chemistry)
- Textbooks of organic chemistry have not substantially changed since the 1960s; we tend to teach what we learned without regard to the rapidly advancing frontier of novel chemical reactions presented daily in the literature

Here too, this list is not exhaustive. Ask any student or instructor of organic chemistry to describe what is good and what is not so good about organic chemistry classes; the variation in responses will likely be great.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

Several problems associated with undergraduate chemistry education in general have been described in the literature, as summarized by Gilbert (*1*). These problems include the following:

- A perceived overload of content in many chemistry curricula (*2*, *3*); many instructors simply try to cover too much content in the available time
- Content is usually taught without pedagogical attention to helping students make connections between other content areas or everyday life
- Poor transfer of knowledge and skills from one course to the next, or from one discipline to another (*4*)
- Emphasis of content is broad and shallow at introductory levels and does not build an adequate foundation for more advanced studies in the field (*5*)

A number of corrective approaches have been developed to address these problems, from teaching chemistry in particular contexts (*1*) to devising a more logical flow of topics presented in first year courses (*6*) to complete reorganization of the entire curriculum (*7*).

At South Dakota State University, the Department of Chemistry and Biochemistry has expanded the discussion from what appears to be wrong (or right) with one particular sub-disciplinary course into a discussion of what is wrong (or right) with the curriculum as a whole. The objectives of this discourse were centered on providing a coherent picture of the disciplines of chemistry and biochemistry in introductory coursework, as well as create a laboratory learning environment where students from different years of study interact and form a community with cooperative activities created to give hands-on work with advanced instrumentation. Some questions we pondered included how the two disciplines (chemistry and biochemistry) differed and were alike; what a holistic approach to teaching and learning in these disciplines would look like; and how to address the issue of lack of preparation for highly quantitative problem solving in the first year of study. Other issues were brought to bear on the conversation, including the reduction in credit hours required for graduation, teacher training, and how to maximize students' learning throughout the curriculum.

Such types of discussion are not new among academics, given that several position statements and research reports are found in the literature (*7–9*). However, much of what appears in the literature is devoted to describing the question from the student's point of view: how can chemistry instructors create innovative curricula to maximize student learning and engagement (*10–13*)? Research related to student learning and engagement in chemistry is vast, but some major themes arise from even a brief review of that body of work:

- Students have demonstrated that solving quantitative problems is an easy task, but describing their answers in terms of the chemical principles guiding the problem is difficult (*14–17*)
- Student conceptions of chemical principles appear to be highly contextualized; *i.e.,* knowledge learned in one course does not necessarily or easily transfer to other courses (*18*)

- Teaching strategies to combat student learning difficulties may not be effective because we as yet do not fully understand the nuances of these learning difficulties (*19*)

Rettich, *et al.* (*20*) proposed a plausible explanation of students' struggles to understand chemistry. If a student's introduction to the discipline at the university level is a full year of general chemistry followed by a full year of organic chemistry, many will leave that experience with the idea that the two courses are not related in any meaningful way. Each course consists of a conglomeration of facts and theories without tangible connection. Even the types of problems solved in each course are vastly different and apparently disjointed. Moreover, the quantitative rigor associated with most second semester general chemistry courses may overwhelm students with inadequate math preparation, leading to further difficulties in learning the subject and solving problems. In some instances, the problem is exacerbated by a heavily quantitative approach when an adequate conceptual foundation has yet to be built (*e.g.*, equilibrium processes without a firm understanding of acid/base theories). Some (*21*) have suggested that second semester general chemistry provides no better preparation for first semester organic chemistry (the next course at most institutions) than a year of high school chemistry. Although this particular viewpoint is from the 1930s, we are of the opinion that some topics covered in traditional second semester general chemistry courses *are* relevant to topics learned in organic chemistry, but the question remains as to why these topics shouldn't be taught congruently using organic and inorganic contexts. Further, the second semester general chemistry course has become even more quantitatively rigorous since the 1930s, which may exacerbate the problems associated with student preparedness for organic chemistry. These points raise the question of where organic chemistry best fits into the curriculum, and further illustrate the need to increase conceptual understanding among students of chemistry from the beginning of their education.

Coppolla (*22*, *23*) argued that the teaching of general and organic chemistry would appear more logical to students if a blended approach were adopted in the classroom. He suggested that the priority of the undergraduate chemistry curriculum must be the guiding or foundational principles of the discipline, and these principles should be illustrated with examples from all contexts of the discipline. A pedagogical approach built on this assumption should help students to understand that chemistry is chemistry, no matter which chemistry course one is enrolled in; student belief in the compartmentalized, separated sub-disciplines of chemistry should begin to disappear and conceptual mastery increases.

Curriculum reform measures which address these issues in organic chemistry education have mostly been in two forms: the organic first approach and the blended/integrated approach. Curricula that follow the organic first approach typically either eliminate general chemistry altogether, or add an advanced general/inorganic course after the year-long study of organic chemistry taken in the freshman year. The blended/integrated approach typically blends the topics covered in general and organic chemistry courses, with a focus on the unifying principles of chemistry as a discipline. Each model has been implemented at various types of institutions, from the primarily undergraduate college (*e.g.*,

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

Juniata College) to the research-intensive university (*e.g.*, Indiana University). Each comes with perceived advantages and disadvantages as well (*e.g.*, better student conceptual understanding at the expense of faculty time to create blended or integrated courses).

Comprehensive Curriculum Development at South Dakota State University

Each pedagogical approach mentioned above is directed toward improving chemistry teaching and learning at the undergraduate level, but each approach virtually ignores the laboratory component so often required as a co-requisite course. A comprehensive approach to curriculum revitalization is thus required, one that involves not only the lecture component but also the laboratory component as well. The confluence of several factors (a new strategic plan, new ACS guidelines for certification, and the need to improve laboratory instruction) prompted the chemistry and biochemistry faculty at South Dakota State University to revisit its undergraduate chemistry curriculum, with the goal of devising a comprehensive, innovative, and modern curriculum for future chemists and biochemists.

The Department of Chemistry & Biochemistry at South Dakota State University consists of 19 faculty members: 10 are tenured/tenure-track, three are research faculty, and six are lecturers. With the exception of the six lecturers, all other faculty members are research active. As of 2011, there were a total of 85 undergraduate majors (both chemistry and biochemistry), and 55 graduate students. Most of the graduate students are appointed to teaching assistantships for general and organic chemistry laboratory courses; a few others are appointed to biochemistry laboratory courses. The department is the only chemistry department in the state to offer the Ph.D. in chemistry. In summary, the department is a medium sized, research focused department.

Several years ago the Department of Chemistry & Biochemistry underwent an external review of the departmental strategic plan. As part of the review, a panel from the American Association for the Advancement of Science (AAAS) recommended that the department "undertake a thorough redesign of the American Chemical Society (ACS)-certified undergraduate degree – the changes should be both broad ranging and fundamental" (*24*). Recent national and state efforts to improve STEM education, of which chemistry represents a major discipline, indicate that any redesign must result in better teaching methods (*25*).

Around the same time as the development of the new departmental strategic plan, the ACS announced sweeping new changes in the guidelines used to certify undergraduate chemistry degree programs. The updated guidelines, presented by the Committee for Professional Training (CPT), provided more freedom for departments to stress their individual strengths within the curriculum, as well as more freedom for student progression toward the certified B.S. degree.

Finally, the SDSU chemistry and biochemistry faculty had lamented for some time that undergraduate laboratory education must be improved. It was agreed that such improvement must include the following aspects: more computational methods in lower-level undergraduate laboratory courses; more significant student opportunities for hands-on work using advanced instrumentation; incorporation of experiments with more relevance to current problems or research activity; and creating a sense of *esprit de corps* among our undergraduate majors.

Faculty discourse related to curriculum revision was further informed by student feedback. Our students told us that the mathematical rigor of the chemistry and biochemistry degrees was daunting, even in early courses, and they perceived a lack of specificity in the topics during the first two years related to their interests (*e.g.*, biochemistry or analytical chemistry). Students also believed that the first years of instruction were very broad, and lacked the depth that they needed in order to achieve a better understanding of the discipline.

Based on recommendations from the AAAS review panel and in light of the updated ACS guidelines for undergraduate education, the department began to construct a new curriculum in the spring of 2009. Focus was placed on the first two years of instruction as a starting point. The two authors, who were usually appointed to teach honors/majors general and organic chemistry, were charged with creating a sequence of courses which would address the issues discussed in the preceding paragraphs. Over the spring and summer of 2009, the authors discussed and removed redundancies in the four traditional courses, ordered topic coverage in terms of a more perceived logical flow, and discussed how the laboratory component should change to reflect changes in the lecture component. The first implementation of the revised first four courses and laboratory courses occurred during the fall 2009 semester, with 28 students enrolling in the first newly created course.

The first cohort of students to enroll in the course experienced a slightly different curriculum compared to subsequent cohorts. During the first implementation of these courses, the fourth course was not created as a stand-alone laboratory course. Rather, it was a more quantitatively rigorous course devoted to concepts such as equilibrium, thermodynamics, and kinetics. As the more advanced courses in the chemistry curriculum were revised, these topics were placed into our newly created physical chemistry course. Given that the new introductory courses were intended for chemistry and biochemistry majors, changing the fourth semester course into a laboratory course would not compromise students' understanding of the quantitative aspects of equilibrium and thermodynamics. By the time the second cohort of students took the fourth course in spring 2011, the course was converted to the laboratory course we report below.

Design of the new courses and associated laboratories was achieved with significant time commitment and thought devoted to how the "story" of chemistry might be better told, to avoid the problems reported in the literature. As much of the introductory course design occurred in the summer months, the authors were not provided with release time to create the courses. Laboratory exercises which had been used in earlier honors/majors sections were used in the new sequence. Some of these exercises remained unchanged, some were new to the curriculum, while others were converted by the authors into more inquiry-driven activities. New experiments in the first laboratory course were created to bring more hands-on experience working with advanced instrumentation. In terms of

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

converting existing experiments into more inquiry-driven activities, an example is the study of SN2 reaction in organic chemistry. Students in organic chemistry lab traditionally investigate the SN2 reaction in a series of laboratory activities: one focused on alkyl halide structure, one on solvent type, and perhaps one on competition of reactions. These individual experiments were combined into one, two-week experiment where students were instructed to create an experimental procedure which isolated at least two variables associated with SN2 reactions, and to perform the experimental procedure the following week. Student groups were also instructed that no two groups may choose the same variables. Finally, students posted their experimental results to the class website, so that all investigated variables could be addressed in individual laboratory reports, regardless of whether students manipulated a variable in their experiment or not.

Design and Implementation

Based on student feedback, new freedoms from the ACS in terms of coursework for the certified curriculum, the results of the external review, and a few literature precedents, we adopted what we believe is a novel approach to introductory undergraduate chemistry education. The first two years for chemistry and biochemistry majors at SDSU was restructured, with the understanding that not all previously reported curricular change models in chemistry would work for our institution. We opted for a blended, atoms-first approach, beginning with a qualitative view of the discipline with continual focus on its guiding principles, and from there build in quantitative rigor through the remaining three semesters.

By necessity, the laboratory component of the curriculum was also restructured, following a similar approach. Here, we begin with an introduction to the common laboratory techniques used by practicing chemists in their everyday work. Included in this introduction to techniques is the use of modern instrumentation, including UV-Vis spectroscopy, IR spectroscopy, NMR spectroscopy, mass spectrometry, HPLC, gas chromatography, and atomic absorption spectroscopy. Students work extensively with this instrumentation in their first semester laboratory experience, with the expectation that its continued use over four semesters will increase both their mastery of the techniques and their motivation for continuing study in chemistry or biochemistry. Another unique approach we adopted was to make the four semesters of laboratory increasingly inquiry-oriented; that is, by the second and third semesters, students are designing and implementing experiments, analyzing the resultant data, and recommending new experiments. The fourth semester laboratory course is designed as a stand-alone capstone course, intended to springboard students directly into faculty research labs for their undergraduate research experience.

Perhaps the most novel approach we adopted in developing the laboratory courses is the use of peer mentoring. First-year students share laboratory space and equipment with second-year students, with the goal of creating a community of practice (*26*, *27*) in which the more experienced second-year students help teach the first-year students the necessary techniques and instrumentation, with all students working toward a common cause. The collaborative climate in this model is intended to mimic the interactions one commonly finds in a functional research laboratory; students enter this setting and gradually increase their responsibilities to the group as knowledge and skills are acquired.

The following sections describe the courses we developed and implemented, beginning with the lecture component, followed by a description of the laboratory component. In each instance, we will describe our goals for the courses, the topic coverage of each, and how the two link together.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

The Lecture Sequence

The updated curriculum at SDSU focuses on the foundational principles of chemistry, beginning with a qualitative picture of the discipline and building toward quantitative rigor. The goals which guided the development of these courses were:

- Present a cohesive storyline of chemistry as a discipline while minimizing traditional contextual boundaries
- Teach students to first think in terms of describing the discipline with concepts, then describing it further in terms of mathematics
- Allow students with weaker mathematics preparation to hone these skills with collegiate level math courses without fear of failure in the chemistry courses
- Create a sense of citizenship and belonging for students within the department
- Build the courses from an atoms-first approach, while eliminating repetition from high school training
- Allow students to enter more advanced chemistry courses earlier in their academic training

The course sequence is as follows: CHEM 115 (Atomic and Molecular Structure); CHEM 127 (Structure and Function of Organic Molecules); and CHEM 229 (Transformations of Organic Molecules). CHEM 237L (The Sophomore Laboratory Experience) will be discussed in the laboratory section of the chapter. Table 1 outlines the topic coverage in each of the first three courses. All departmental majors enroll in this course sequence. It is strongly suggested that students who enroll in these courses have at least one year of high school chemistry or a semester of advanced placement chemistry. We presume that students with an interest in the discipline and with this level of high school training have mastered such concepts as stoichiometry, unit conversions, nomenclature of inorganic molecules, reaction classifications, and basic atomic principles. This assumption thus allows us to eliminate these topics in the course sequence we offer. For students who require remediation in these skills, the instructors will provide individual assistance; however, students are made aware

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

from the first day of the course the expectations of the instructor, and the minimal knowledge required to be successful in the course. The department does also offer the standard course sequencing of general chemistry I and II followed by organic chemistry I and II; these are intended as our service courses, and incoming chemistry or biochemistry majors who do not feel prepared for the majors' sequence may enroll in these classes to build their conceptual understanding to the expected levels.

The reader will note the appearance of the word "structure" in two of the three courses; the use of this term is purposeful. One of the guiding principles of chemistry is the structure/function relationship, and from the beginning of these courses the instructors capitalize on this principle. CHEM 115 lays a foundation of the subatomic particles that construct the atom, and in turn how atoms interact with each other to form molecules. Several bonding theories are introduced in the course, including molecular orbital theory as applied both to inorganic and organic molecules. Once students understand how molecules are formed, attention then shifts to the structure of molecules and how individual structural motifs lead to unique attributes of molecular behavior. For instance, students come to understand that different conformations of molecules, a consequence of bond rotation, have different energies, some more stable than others. Students are also introduced to the various stabilizing influences related to structure, such as resonance capability, induction, and hyperconjugation.

Students also discuss how molecular structure directly influences the attraction and repulsion of other molecules via the concepts of intermolecular forces. Students learn the ability to analyze molecular structure and make predictions about solubility in different types of solvents. They begin to identify where electrons are plentiful, and where they are lacking, which is the very foundation of understanding organic chemistry. They are also introduced to the concept of chirality, and how three-dimensional shapes of molecules influence their behavior.

CHEM 127 builds upon the content covered in the previous course to expand the structure/function relationship using acid/base models, including hard/soft acid-base theory (HSAB). Here, students also develop an understanding of the different phases of matter and the different behavioral and reactive properties of molecules in each phase. Before moving on to more advanced organic reactions, a brief, qualitative description of thermodynamics and kinetics is covered, couched in terms of reactive intermediates encountered in classical organic chemistry. At this point, students should now have constructed a foundational understanding of different concepts as they relate to reaction chemistry; this understanding is tested through a discussion of classical organic substitution and elimination reactions. One of the most challenging aspects of substitution/elimination reactions for students is the idea that as reaction conditions are varied, the mechanistic pathway and outcomes are changed. For most students, this subject represents the first true critical analysis of reactions they will have encountered; they must become familiar enough with the variables which change reaction pathway and outcome to discuss in depth why these variables exert the changes they do. It becomes obvious to the students at this point that, despite previous training, sometimes the most definitive answer to a question begins with "maybe."

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

Table 1. Topic coverage in new freshman/sophomore blended curriculum at SDSU.

Course Name	*Topic Coverage*
CHEM 115: Atomic and Molecular Structure	**Atomic Structure** - structure of atoms; subatomic particles; nuclear chemistry; quantum theory; periodic trends **Molecular Structure** - bonding theories; Lewis structures; structure/reactivity relationships; forces of stabilization **Analysis of Structure** - symmetry analysis; atomic methods; molecular methods **Hydrocarbons** - nomenclature; conformational analysis; stereoisomerism; elementary thermodynamic calculations; elementary reactions **Aromaticity** - Huckel's rule; aromaticity determinants; EAS and NAS; analysis of reactions
CHEM 127: Structure and Function of Organic Molecules	**Advanced MO Theory** - LCAO methods; perturbation theory; HOMO/LUMO applied to reactions **Reactivity of Molecules** - gaseous state reactions; introductory thermodynamics and kinetics; kinetics applied to mechanism determination; classes of mechanisms; selectivity; reactive intermediates **Acidity and Basicity** - definitions and structural characteristics; linking Lewis theory to electrophile/nucleophile designation; HSAB theory; equilibrium **Nucleophilic Substitution and Elimination** - factors influencing mechanistic pathway **Electrophilic Addition** **Oxidation and Reduction** - organic and inorganic contexts
CHEM 229: Transformations of Organic Molecules	**Liquids, Solids, and Solution Chemistry** - solvolysis, solid state organic chemistry **Alcohol and Ether Chemistry** **Carbonyl Chemistry and Chemical Equilibrium** - aldehydes and ketones; carboxylic acids and derivatives; reactions at the alpha carbon; intermediate equilibrium concepts **Organometallic Chemistry** - Coordination compounds; classical syntheses and preparations; newer applications toward organic synthesis **Pericyclic Reactions** **Thermochemistry in Depth** - bond enthalpies; enthalpy of formation; heat capacity; entropy; Gibb's free energy; applied to each reaction type
CHEM 237L: Sophomore Laboratory Experience	**Faculty Driven Research Projects**

Once the elementary organic reactions have been learned, the course moves into organic reactions involving the pi bond, including electrophilic addition to the alkenes and alkynes, and a discussion of the unique chemistry of benzene. The course finishes with a treatment of oxidation and reduction in both organic and inorganic contexts.

CHEM 229 represents the classical second semester organic course, with topics ranging from alcohol and ether chemistry to carbonyl chemistry to elementary biochemistry. The course finishes with a more quantitative treatment of thermochemistry, with the intent of providing adequate introduction for students to move directly into physical chemistry in the fourth semester of their study. At this point, students now will have developed the conceptual skills necessary to progress into biochemistry and physical chemistry, meeting the goal of earlier enrollment in advanced coursework.

Throughout the initial three semesters, where warranted, examples related to the guiding principles of chemistry are presented without definitive context; students are shown that oxidation and reduction processes, for example, are described differently by inorganic and organic chemists, but ultimately lead to the same conclusions. Acid/base chemistry is emphasized in both inorganic and organic contexts, further illustrating that the principles do not change; only the context varies.

In the first three undergraduate chemistry courses, we present a more unified story of chemistry allowing the students to develop the ability to apply fundamental chemistry knowledge to varied contexts across the sub-disciplines. Research shows that utilizing methods in the classroom to provide “evidence-based teaching methods” can more effectively motivate students to remain in STEM programs, in particular women and members of minority groups whom have typically dropped from STEM programs in the past (*28*). Retaining these students is critical considering that the President’s Council of Advisors in Science and Technology found that one million additional graduates with STEM degrees are needed over the next decade to fill the growing number of jobs that require these skills.

The Laboratory Sequence

As part of the Report to the President (*25*), a vital recommendation posited that government agencies “advocate and provide support for replacing standard laboratory courses with discovery-based research courses,” a call that echoes previous laboratory reform initiatives (*29–31*). Historically, the purpose of undergraduate laboratory courses has been to provide hands-on experiences for students, who in consequence develop specific laboratory skills while verifying certain fundamental chemistry principles. We observed that students typically experienced the hands-on learning, but we questioned whether minds-on learning occurred. Science educators have written in the past about the unique opportunities that the laboratory course provides to engage students in the process of investigation (*32*), and several curricular modifications concerning laboratory instruction have been reported in the literature.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

One example is the use of inquiry based laboratory instruction (*33*, *34*). The premise of the inquiry laboratory experience is to give students a better idea of the planning, execution, and evaluation of results of an experiment; the ultimate goal is to provide students with a "real-life" experience, much like that which a practicing scientist experiences on a daily basis in his/her normal workday. Literature summaries of the influences of such a curriculum generally reach positive conclusions: in some studies, students attain higher laboratory skill (*35*), and in some students were reported to attain greater conceptual understanding (*35*, *36*).

The use of blended or integrated laboratory exercises has also been reported in the literature (*37–39*). The blended or integrated laboratory exercise is intended to apply principles from several concepts toward one solvable problem in either one or several laboratory periods. One trait of these integrated laboratory experiences is the level of inquiry involved in them; most examples reported in the literature rely on guided inquiry (*40*). In other words, students are given a problem description and a listing of the available tools, suggested experimental procedures, and hints to the outcomes of these procedures. In guided inquiry exercises, the onus of scientific work is placed directly on the student, such that they become scientists in training rather than laboratory technicians.

Another innovation in laboratory curriculum efforts has been to introduce students to advanced instrumentation early in the degree program (*41–43*). In typical undergraduate chemistry programs students often are not introduced to sophisticated instrumentation until the third or fourth year in the degree track, if at all in some cases. The premise of a prior federally funded laboratory teaching program was that students acquire a better appreciation and understanding of instrumentation if they were exposed to that instrumentation at multiple times during the undergraduate program. Evaluative outcomes of that program showed that students, when given the opportunity to work with more advanced instrumentation (HPLC & CE), left the course with an enhanced understanding of these techniques (*41–43*). An additional outcome of that study described students as being more confident in their use of the instrumentation and being empowered to utilize the instrumentation in future experiments.

The overarching goal of the laboratory redesign for the first four semesters at SDSU was to closely mirror the process of entering a working research laboratory as a functioning member of a research team. To achieve this goal, three guiding principles were considered:

- Research is a process that involves a community of practitioners with varying roles and responsibilities to the community (*27*)
- Learning laboratory techniques should intellectually progress from mastery of skills toward authentic inquiry
- Research instrumentation provides greater insight into future learning activities for students who intend to pursue careers in the chemical or biochemical sciences

The programmatic structure, informed by these three guiding principles, is described below.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

Creating a Community of Practitioners

Developing a community of practitioners where all members participate requires that students interact in formal learning environments. Interaction between CHEM 115L and CHEM 229L students begins by co-enrolling students from each course into one laboratory section. Each laboratory section was created to accommodate 12 students from each course, with a maximum enrollment in each lab section of 24 students. Two teaching assistants are present in the laboratory simultaneously; one supervises the CHEM 115L students while the other supervises the CHEM 229L students. Each week, the instructional team (consisting of teaching assistants and faculty instructors) propose purposeful interactions between the groups of students based on the respective procedures in use that week. This model is based in part on Lave and Wenger's (*27*) theory of legitimate peripheral participation, and in part on Liebig's model of research laboratory hierarchy (*44*).

The theory of legitimate peripheral participation purports that those who join a community of practice increase their participation and status in the community through involvement in at least one of the following experiences:

- Proving themselves by doing work which alone is considered unimportant, but is vital to the continuity of the practice of the community and the community itself
- Entering the community at its periphery, where low-responsibility tasks are given that remain vital to the continuity of the community and its purpose
- Gaining the confidence of more senior members of the community by learning the mores of the community and making contributions to its continuity
- Increasing in community status by continually adopting roles which have greater responsibility to the community's output and continuity

In our model, CHEM 115L students serve as novice chemists, entering the community of practice at its fringe, while CHEM 229L students serve as experienced chemists. Similarly, in their freshman year, current CHEM 229L students contributed to the community as novice chemists by interaction with the prior student cohort. Now, during the sophomore year, the more experienced CHEM 229L students serve as mentors to CHEM 115L students, providing experience and guidance in several areas: standard laboratory techniques, the use of instrumentation in appropriate instances, and other ideas related to progress in a laboratory setting. In turn the CHEM 115L students, by performing peripheral duties, learn from the experiences of their older colleagues to develop the laboratory skills and knowledge required to increase rank and responsibility within the community, knowing that they will be the experienced members of the community in the following year. This structure implies that each group has separate responsibilities that relate to the completion of common experiments or projects.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

The role of graduate teaching assistants and instructors of the laboratory courses is best explained using Liebig's hierarchical model. The model is based on a pyramidal shape, where at its base are undergraduate research assistants just beginning their research experiences, and at its apex is the research advisor, from whom research ideas and projects are derived. In between these strata are more advanced undergraduate students, beginning graduate students, senior graduate students, and post-doctoral researchers. Liebig's model is congruent with the theory of legitimate peripheral participation, in that to ascend the pyramid of the research lab hierarchy a student must prove her/his abilities to more senior members, who have already accomplished ascension by virtue of their previous work. In our model, the instructors of the laboratory courses serve as the research advisor, and graduate teaching assistants are equivalent to post-doctoral researchers. The instructors' responsibilities are to devise activities for students in the lab courses, and the graduate teaching assistants are present to provide advice or expertise when students encounter problems completing their given activities. In short, everyone has a place in the community, each working toward achieving its common mission.

It is important to note that merely placing all the members of the community together in the same location will not in itself ensure that there is sufficient interaction to promote learning or skill acquisition among its younger members. Directed activities that bring CHEM 115L and CHEM 229L students together to achieve a common goal foster the interactions necessary to encourage community building. The model continues into the second and fourth semester laboratory courses (CHEM 127L and CHEM 237L, respectively). Interactions between students in these courses are strengthened as lab skills are mastered, instrumentation is used, and more inquiry-driven activities are completed.

By necessity, the community of practice extends beyond the teaching laboratory. If one of the goals of this model is to train students to understand the research process, a vital component to the model's success is providing students with insights into research that occurs locally. One procedure used to help meet this goal occurs during CHEM 115: faculty seminars. Students in CHEM 115, as part of formal instruction in the course, attend short seminars given by research active faculty members in the department and submit review papers of the presentations. Each research active faculty member in the department participates in this process. Our model introduces first semester freshmen to the departmental faculty, presents an overview of the research initiatives within the department, and encourages reflection on how the community we strive to create continues beyond the first four courses.

Moving from Verification to Inquiry

During the first laboratory course, CHEM 115L students learn basic techniques for using the instruments, acquiring needed laboratory skills, and reviewing basic stoichiometry calculations; as such CHEM 115L pedagogy follows a hands-on, verification approach. The skills listed provide chemistry

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

and biochemistry majors with initial information and practice in laboratory methods to help them move from the periphery toward the center of the research community. Upon enrolling in CHEM 229L, students have by this point attained the skills necessary to complete standard laboratory activities, such as distillation or titration, and this presumption guides the pedagogy of that course with a more exploratory aim. CHEM 229L activities require students to consider how an experiment is designed and implemented, including identifying the instrumentation needed to obtain data and how best to analyze that data. The schedule of experiments for both CHEM 115L and CHEM 229L are shown in Table 2. In summer 2012, new experiments for CHEM 115L will be created with the purpose of training students on advanced instrumentation. A thematic approach will be taken; in other words, the experiments designed to introduce students to instrumentation will have a common theme. This approach will demonstrate to students that a variety of instrumental techniques are available to answer common laboratory problems, and will also teach students which instruments are appropriate to use for individual experiments. Our approach supports the continuity of the practicing community by beginning with tasks that appear menial, but are important to the successful completion of the project as a whole. These tasks allow the CHEM 115L student to be a functioning member of the community from the beginning, providing a sense of inclusion within the department that in turn encourages them to continue in the discipline. Students learn to properly prepare and standardize solutions, titrate solutions, master purification techniques (*e.g.,* distillation and recrystallization), and other volumetric skills. They also gain experience using instrumentation, and interpreting analytic results.

Following the training on instrumentation received during CHEM 115L, students begin the second semester (CHEM 127L) by continuing to use the advanced instrumentation with one change; students develop a portion of the experimental procedures through a guided inquiry process. For example, in the first several experiments, CHEM 127L students create procedures for analyzing experimental data. In other activities, students design the experiments. This approach becomes more inquiry-oriented as students progress through the course sequence. We believe that our model of laboratory instruction assists students in building confidence and showing creativity in the laboratory.

During CHEM 229L, the guided-inquiry approach becomes a more significant component of each experimental activity. For instance, by the end of CHEM 229L, students design and implement a synthesis of benzocaine. Although this is a standard laboratory activity in traditional organic chemistry labs, students spend the first laboratory period designing the synthesis without assistance from a textbook, the literature, or the internet; this approach aids in the originality of the design and encourages reflective thought about reactions learned over the span of their organic chemistry training. Further, students are encouraged to critically evaluate their strategies in terms of cost and availability of starting materials. These behaviors are similar to those of a practicing organic chemist in her/his own laboratory. CHEM 229L students assume greater responsibility in the control of multiple variables of the experiment rather than just one. Incrementally increasing the inquiry orientation of the laboratory experience provides CHEM 229L

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

students with the ability to delegate the responsibility of spectral data acquisition and interpretation to CHEM 115L students. CHEM 229L students, based on their knowledge of instrumentation, indicate which tests CHEM 115L students should complete. Thus, CHEM 229L students must understand which instrumentation is appropriate to the laboratory activity and why it is advantageous to use. The progressively more inquiry-oriented pedagogy used through the second and third semesters prepares students for the fourth semester laboratory course, described below.

Using Advanced Instrumentation Early in Academic Training

During the four courses, students are introduced to and conduct laboratory experiments with advanced instrumentation. The advanced instrumentation used in support of the instructional model was chosen based on two factors: the perceived need of these instruments in the teaching laboratory, and the rate of use of these instruments in departmental research activities. Since the capstone of the laboratory curricula is the infusion of faculty-driven student projects in CHEM 237L, it is necessary to familiarize students with specific types of instrumentation and the appropriate circumstances under which to use it. Therefore, gas chromatography (GC), high-performance liquid chromatography (HPLC), FT-IR, ultraviolet-visible (UV-Vis) spectroscopy, atomic absorption Spectroscopy (AA), mass spectrometry (MS), and nuclear magnetic resonance spectroscopy (NMR) were chosen by faculty as the most important instruments that a beginning undergraduate chemistry or biochemistry major should understand.

During CHEM 115L, students perform experiments designed to introduce the theory and application of scientific instrumentation. Students learn the theoretical basis for the instruments while simultaneously using the instrumentation to collect and analyze data. By the end of CHEM 115L, students understand the purpose of each instrument, as well as the type of sample appropriate for testing with each. The basic laboratory experiments which involve instrumentation help to build students' confidence in the use of the instruments and the interpretation of data obtained from them. As described by Bushey (*42*), continued use of scientific instrumentation in lab settings increased student confidence and empowerment to use these instruments in future applications and different settings. The instruments are used during multiple experiments throughout the four semester laboratory sequence, to ensure that students remember their prior training and interpretation skills. Because these instruments are extensively used in both advanced laboratory courses and in departmental research laboratories, the introduction of students to this equipment and its use at this stage of a student's cognitive development is particularly appropriate.

Table 2. Experiment list for CHEM 115L and CHEM 229L, Fall 2011 semester. Twelve students from each course enroll in the same laboratory section.

Date	*CHEM 115L*	*Interactions*	*CHEM 229L*
6 September	Syllabus Radioactivity Synthesis of Aspirin	Introductions Team building exercises	Syllabus Expectations
13 September	Solution Preparation Laboratory Techniques	Standardization of Bleach	Oxidation of 2-methylcyclohexanol using NaOCl
20 September	FTIR Theory Analysis of Aspirin	FTIR of starting materials/products of E.A.S	Iodination of Vanillin (E.A.S.)
27 September	No Lab		Aldol Reaction
4 October	FTIR Lab	FTIR analysis of esters GC analysis of esters	Synthesis of C4 and C5 Esters
11 October	Beer's Law and standard method Copper Penny	Is Methyl Red UV active?	Synthesis of Methyl Red
18 October	Chromatography	HPLC of penicillin	Drug Discovery 1: The Penicillins
25 October	NMR Theory & Training	HPLC of penicillinic libraries	Drug Discovery 2: The Penicillins
1 November	NMR		Synthetic Design: Benzocaine
8 November	NMR	^{1}H NMR of starting materials and product of benzocaine synthesis	Synthetic Design: Benzocaine
15 November	Mass Spectrometry Theory		Clean Up
29 November	MS		Final Lab Meeting
6 December	Identification of Unknown Material		

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

The Fourth Course

The fourth laboratory course, CHEM 237L, was designed to bridge formal laboratory instruction and authentic research participation. In CHEM 237L, student projects are derived from and aligned with departmental faculty research activities. CHEM 237L carries a load of two credit hours, providing six laboratory hours per week for students to design, implement, analyze, and modify experimental procedures to answer faculty research questions. The instructor of CHEM 237L solicits proposals from research active faculty in the summer to use as projects for CHEM 237L students in the following spring semester. Projects are categorized into two types: problem solving or exploration. The problem solving type of project affords the expectation that students will provide a "final" conclusion from their work. An example of a problem solving project follows.

> There have been news reports and a few studies showing that trace levels of benzene have been found in vitamin C (ascorbic acid) containing beverages, such as orange soda, that use sodium benzoate as a preservative. The mechanism has not been studied, but it appears that temperature, time, and exposure to sunlight all play a role. Propose a mechanism for the formation of benzene in these beverages and study the effect of relevant parameters on this chemical system.

Exploratory projects, on the other hand, afford students with a starting point for inquiry, but the types of modifications students suggest are open to their creativity. A specific targeted answer is not expected and the resulting conclusions provided by students could develop into additional projects for future students. An example of an exploratory project follows:

> Suggest modifications of phthalocyanine dye molecules that will produce properties of interest for dye-sensitized solar cells. Students will be given a starting point of the optimized base phthalocyanine and directed to suggest and test structural modifications to the dye molecules.

Our model provides the faculty with direct input into the curriculum of the fourth semester, and greater interaction with potential future undergraduate research assistants. The projects allow students to maximally utilize the advanced instrumentation they have been working with during the first three semesters of the sequence. Projects of this caliber also provide a first step into truly authentic research activities.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

Table 3. Timeline and activities in CHEM 237L, the bridging course from formal instruction to the research process.

Week	*Activities*	*Outcomes*
1	-Faculty presentations of projects -Organize groups and determine first steps to for the project -SciFinder & other literature search presentation -Examine an example literature review	-Rough draft of literature review due in lab -Weekly memo due discussing group activities
2	-Consultation with faculty and graduate students -Assessment of important variables to test -Initial development of experimental design	-Preliminary experimental design due in lab for review -Weekly memo due discussing group activities
3	-Consultation and feedback regarding the experimental design -Preparation of appropriate materials following approval of experimental design	-Reconstructing experiments as informed by data analysis -Weekly memo due discussing group activities
4-7	-Conducting initial set of experiments -Preliminary data analysis -Reconstructing experiments as informed by data analysis	-Weekly Progress reports on experimentation due
8	-Scientific conference for oral presentation of progress on experiments -Formal presentation due discussing progress of research to faculty members and peers	-Oral presentation to faculty and peers
9-11	-Conducting final set of experiments -Concluding data analysis and interpretation	-Initial construction of final report -Weekly Progress reports on experimentation and analysis due
12	-Presentation of findings to faculty members and peers (poster)	-Final reports due -Participate in SDSU undergraduate research event -Publish in SDSU Undergraduate journal

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

Table 4. Timeline for Faculty Research Summer Preparation of Projects

Week	*Activities*	*Outcomes*
1	-Initial meeting to establish a baseline of the requirements for the faculty member involved in a project	-Initiate brainstorming activities for potential projects – create initial list
2	-Brainstorming meeting to create possible projects	-Increase the potential progress list
3	-Identify projects which best fit the condition of the Sophomore Research Experience	-Write concise research questions for the identified projects
4	-Scrutinize research questions to focus the project	-Final research questions for the identified projects
5	-Define possible student needs for conducting experiments to answer identified projects	-List of materials and instrumentation identified
6	-Identify methods which enable/encourage/ nudge students toward starting a project	-Craft pedagogical approaches for initiating student interest
7	-Identify initial primary literature materials that would initiate student inclusion into the project	-Compile 3-5 research articles describing the basis for the research
8	-Finalize the potential research project	-Create a summary folder for submission to expert panel

The pedagogical process for CHEM 237L involves several steps, described in Table 3. First, students meet with research faculty members to discuss the background and goals of the proposed projects. Students then assemble into teams based on common interest in a particular research project. During the first two weeks of lab, each group identifies and reads primary literature regarding the project based on preliminary literature references suggested by the faculty members. A literature review is then completed by each team. Each week of the semester, teams provide a memo outlining the activities of the prior week to research faculty, the CHEM 237L instructor, and the CHEM 237L teaching assistants. Students design and implement experimental procedures to address the research questions based on continual feedback from several sources: faculty members, graduate teaching assistants, graduate research students, and the CHEM 237L instructor. Students are also responsible for data collection and analysis. At mid-semester, all groups present their initial findings in a conference-type setting, with CHEM 127L students and departmental faculty attending. Upon consultation with the faculty member, students return to the lab for the final weeks of the course to complete experimentation and flesh out their previous findings. During the final week of the course, students present their findings in a poster session at the university sponsored Undergraduate Research Day.

The success of the sophomore laboratory experience depends on the ability of faculty members within the department to satisfactorily create projects that meet the two project types previously mentioned. During the summer project development process, the CHEM 237L instructor and research faculty work together through the following timeline to create several potential projects for CHEM 237L using the methods described in Table 4. In doing so the number of potential projects for the course can be increased, and those projects not selected can be reconsidered during a later semester. Following this plan, faculty submit their projects to the CHEM 237L instructor for project selection.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

Concluding Remarks

Currently, formal evaluation procedures have been implemented to determine the impacts of our curricular redesign; some variables under examination include critical thinking ability, retention of concepts and skills, time of entry into undergraduate research participation, and perpetuation in both the research laboratory and completing the B.S. degree. The latter two metrics will be measured and compared with departmental records from previous academic years to determine if our approach propels students into undergraduate research earlier, and keeps them active longer. Further, we will use the CAT, or Critical Thinking Assessment Test (*45*), to determine whether our model improves students' critical thinking abilities by comparing CAT results with students who experienced traditional instruction in the freshman and sophomore lecture and laboratory courses. We expect the following outcomes:

- Greater understanding of chemical principles which guide the design and implementation of experiments
- Greater application of chemical principles to solve problems in novel contexts both in introductory and advanced coursework
- Knowledge of instrumentation and the appropriate circumstances for its use
- Increased creativity in laboratory work and lecture learning
- Increased and earlier participation in authentic undergraduate research activities
- Increased retention of chemistry and biochemistry majors

These outcomes require rigorous assessment, which is an ongoing process. Some early assessment outcomes have shown that students who take these courses increase their confidence levels in asking questions, developing and using models, planning investigations, analyzing data, creating explanations, and engaging in argumentative discourse based on experimental evidence. Some quotes from students to support these assertions are shown below:

> "Data obtained from the instruments were just numbers; we had to interpret the data and determine its significance. Given that we had

> to report back to the faculty member who directed our project, it was important to us that we presented our findings properly."
>
> "Seeking understanding is the core of science. In these courses I learned to find out what is already known about a topic by doing a literature search, which then helped me to think about what experiments I should do to fill in the gaps. And we had to prove that experiments worked or didn't, and explain why they worked or didn't."
>
> "Constructing calibration curves was the vital model that we used to determine our experimental outcomes. This was really helpful in designing the next steps of the project. This project also helped me to understand the role of mathematics, especially in serial dilutions and calculation of concentrations."
>
> "At the beginning of the project, I wasn't sure what to communicate or who to communicate it to. As we moved through the weeks of the semester, and we used instruments to analyze our experiments for success, it became clear what data was important and what wasn't so important. Talking about the outcomes with the TA, my lab partners, and the faculty member were very helpful in seeing how the whole process of lab work goes, how all these things come together to give a unified whole of research and science."

Anecdotally, we have noted some positive changes in student attitudes toward research participation compared with previous years in the traditional sequence. First, of the 28 students in the first cohort to complete the sequence, six remained at SDSU to participate in research during the summer following CHEM 237L. Three of these six participated in projects which were a continuation of the project they investigated in CHEM 237L. Four of the 28 were placed into competitive undergraduate research fellowships in national laboratories or industrial settings. Additionally, three other students have begun the process of finding research opportunities on campus in the fall 2011 semester. In total, nearly half of the first cohort either has participated, or will participate this academic year, in some form of research activity at the completion of their sophomore year. For the conventional laboratory instructional methods used in previous years, most undergraduate research assistants (83% according to departmental records) did not begin authentic research participation until the second semester of their junior year. In terms of comparison, the number of students from the first cohort who became involved with undergraduate research at the end of the sophomore year represents a 48% increase based on students from the 2010-2011 academic year. Furthermore, these students engaged in undergraduate research on average two semesters ahead of students who took the traditional courses in 2010-2011. We believe that our laboratory model is partially responsible for earlier entry to authentic research activities. Informal conversations with students who have completed the laboratory sequence indicate that they feel more advanced in their thinking and skills attainment than their peers who completed the traditional

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

laboratory sequence. Further, most have stated that the new curriculum was far more interesting and engaging than that reported by their peers in the traditional courses.

We fully acknowledge that the curriculum we described here will not neatly fit every other institution of higher learning. We do suggest, however, that readers take the components which may easily adapt to their institutions and try them out. For instance, it may be practical for an organic chemistry instructor to collaborate with an analytical chemistry instructor to devise a unit of study related to one guiding context, or to devise a collaborative laboratory exercise that brings students from each course together. We also strongly encourage individual reflection and collective discourse about the teaching of all sub-disciplines of chemistry among faculty members. We believe that our pedagogical model will be effective in reaching the expected outcomes listed in previous sections. We have already observed, even anecdotally, that students persevere in the disciplines as majors, engage in undergraduate research earlier in their academic training, and are successful in advanced coursework. More rigorous assessment data will provide stronger evidence to support our assertions. Even though this model may not be applicable at every institution, we hope that our description will catalyze faculty discourse on curricular improvements which can be achieved at institutions around the country and globe. Only via critical discourse about teaching practices and traditions can we ensure chemistry curricula never stagnate.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

Acknowledgments

The authors gratefully acknowledge the National Science Foundation, Division of Undergraduate Education, for their financial support to purchase instruments for the teaching laboratory (TUES Grant #1044419). We also acknowledge the support and patience of the Chemistry and Biochemistry Department faculty at South Dakota State University. Without their support, the community we describe could not exist. We also thank the first three cohorts of students who have experienced the new curriculum for their willingness to serve as test cases in this pedagogical experiment. Our gratitude also is extended to the graduate teaching assistants who helped in the design and implementation of the model. Finally, we thank the Honors College at SDSU for financial support for tutoring in these courses.

References

1. Gilbert, J. K. *Int. J. Sci. Educ.* **2006**, *28* (9), 957–976.
2. Millar, R.; Osborne, J. *Beyond 2000: Science Education for the Future*; School of Education, King's College: London, 2000.
3. Rutherford, F.; Ahlgren A. *Science for All Americans*; Oxford University Press: New York, 1990.
4. Osborne, J.; Collins, S. *Pupils' and Parents' Views of the School Science Curriculum*; King's College: London, 2000.

5. Roberts, D. A.; Ostman, L. *Problems of meaning in science curriculum*; Teachers College Press: New York, 1998.
6. Yoblinski, B. J. *J. Coll. Sci. Teaching* **2003**, *32* (6), 382–387.
7. Hammond, G.; Nyholm, R. *J. Chem. Educ.* **1971**, *48*, 6.
8. Hoffmann, R. *The Same and Not the Same*; Columbia University Press: New York, 1995.
9. Goedhart, M. J. *J. Chem. Educ.* **2007**, *84* (6), 971–976.
10. Farrell, J. J.; Moog, R. S.; Spencer, J. N. *J. Chem. Educ.* **1999**, *76* (4), 570–574.
11. Krause, L. B. *J. Coll. Sci. Teaching* **1998**, *28* (1), 57–61.
12. Landis, C. R.; Peace, G. E.; Scharberg, M. A.; Branz, S.; Spencer, J. N.; Ricci, R. W.; Zumdahl, S. A.; Shaw, D. *J. Chem. Educ.* **1998**, *75* (6), 741–744.
13. Tien, L. T.; Rickey, D.; Stacy, A. M. *J. Coll. Sci. Teaching* **1999**, *28* (5), 318–324.
14. Nurrenbern, S. C.; Pickering, M. *J. Chem. Educ.* **1987**, *64* (4), 508–510.
15. Sawrey, B. A. *J. Chem. Educ.* **1990**, *67* (3), 253–254.
16. Herron, J. D.; Greenbowe, T. J. *J. Chem. Educ.* **1986**, *63* (6), 528–531.
17. Bunce, D. M.; et al. Teaching students to solve chemistry problems – A cooperative research project. Paper presented at NSTA National Meeting, December, 1990, Washington, DC.
18. Anderson, J. R.; et al. *Ed. Researcher* **1996**, *25* (4), 5–11.
19. Taconis, R.; et al. *J. Res. Sci. Teaching* **2001**, *38* (4), 442–468.
20. Rettich, T. R.; et al. *J. Chem. Educ.* **1995**, *72* (6), 638.
21. Wakeham, J. *J. Chem. Educ.* **1939**, *16*, 290–292.
22. Coppolla, B. P. *Chem. Educator* **1996**, *1* (5), 1–8.
23. Coppolla, B. P. *Chem. Educator* **1997**, *2* (2), 1–9.
24. SDSU IPR Report.
25. Report to the President. Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. COLLEGE http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_feb.pdf, February, 2012.
26. Greeno, J. *Am. Psych.* **1998**, *53* (1), 5–26.
27. Lave, J.; Wenger, E. *Situated learning: Legitimate peripheral participation*; Cambridge University Press: Cambridge, U.K., 1991.
28. Seymour, E.; Hewitt, N. *Talking about Leaving: Why Undergraduates Leave the Sciences.*; Westview Press: Boulder, CO, 1996.
29. American Association for the Advancement of Science. *Benchmarks for science literacy: A tool for curriculum reform*; Oxford University Press: Oxford, U.K., 1993.
30. National Research Council. *America's lab report: Investigations in high school science*; National Academy Press: Washington, DC, 2005.
31. Ramaley, J. A. *New Dir. Teach. Learn.* **2009**, *117*, 69–81.
32. Tamir, P. *J. Res. Sci. Teach.* **1977**, *14*, 311–316.
33. Ausubel, D. *Educational psychology: A cognitive view*; Holt, Reinhart, & Winston: New York, 1968.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

34. Shulman, L. S.; Tamir, P. Research on teaching in the natural sciences. In *Second Handbook of Research on Teaching*; Travers, R. M. W., Ed.; Rand McNally: New York, 1973; p 1098.
35. Suits, J. P. *Sch. Sci. Math.* **2004**, *104* (6), 248–257.
36. Lundsford, E. *J. Coll. Sci. Teach.* **2003**, *32* (4), 232–235.
37. Cartwright, H. M. *J. Chem. Educ.* **1980**, *57* (4), 309–311.
38. Baily, R. A.; Zubrick, J. W. *J. Chem. Educ.* **1981**, *58* (4), 368.
39. Goodney, D.; Hudak, N.; Chapple, F.; Brink, C. *J. Chem. Educ.* **1986**, *63* (8), 703–706.
40. Johnstone, A. H.; Al-Shuaili, A. *J. Sci. Ed.* **2001**, *2* (2), 78–80.
41. Bushey, M. *J. Chem. Educ.* **2009**, *86* (3), 332.
42. Bushey, M. *Spectrosc. Lett.* **2007**, *40*, 513–523.
43. Pursell, C. J.; Chandler, B.; Bushey, M. *J. Chem. Educ.* **2004**, *81* (12), 1783–1786.
44. Fruton, J. *Proc. Am. Philos. Soc.* **1988**, *132*, 1–66.
45. Stein, B.; Haynes, A.; Redding, M.; Ennis, T.; Cecil, M. Assessing Critical Thinking in STEM and Beyond. In *Innovations in e-learning, instruction technology, assessment, and engineering education*; Iskander, M., Ed.; Springer: New York, 2007; p 79.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch010

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch011

Chapter 11

Revamping a Second Semester Organic Course To Meet the New ACS Biochemistry Requirements

Jetty Duffy-Matzner* **and Jared R. Mays**

Department of Chemistry, Augustana College, 2001 S. Summit Avenue,
Sioux Falls, SD 57197
***duffy@augie.edu**

This chapter will examine how the Department of Chemistry at Augustana College utilized the guidelines for undergraduate chemistry majors by the ACS Committee of Professional Training to reorganize our two semester organic series to include a biochemistry component. There will be some discussion of the lecture and laboratory revisions made to the series that accommodate requirements for foundational courses in both organic and biochemistry. We found that the traditional methods of teaching an organic series and many of the published organic textbooks would be highly amendable to this process.

Introduction

The American Chemical Society has placed the Committee on Professional Training (CPT) as the guiding body for approving institutions to provide ACS Approved undergraduate degrees. In this end, the CPT develops and administers guidelines for this process. The CPT published new guidelines in the April 2008 (volume 85) edition of the *Journal of Chemical Education* (*1*). This publication was a result of awareness within the CPT of the diversity that was taking place in chemical education and in field of chemistry itself.

The multidisciplinary nature of chemistry is evident all around us, except perhaps in our traditional undergraduate programs. Most of the groundbreaking scientific work in the real world occurs at the interface of chemistry and physics or chemistry and biology. All of the national meetings of the American Chemical Society since Spring 2007 have utilized thematic programming and the ACS has a

In Advances in Teaching Organic Chemistry; Duffy-Matzner, J., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2012.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch011

Multidisciplinary Program Planning Group that emphasizes topics that will appeal to the multifaceted nature of our science (*2*). Thus our society realized in many different venues the importance the diversity of chemistry and that the nature of how we teach our undergraduates needs to reflect some of this diversity as well.

One of the stated goals of the CPT 2008 publication was to "promote the development of modern and innovative curricula by chemistry departments." "Under the new guidelines, the curriculum for an ACS-certified degree consists of *introductory* course work; *foundation* course work to provide breadth; and *in-depth* course work to provide a deeper, specialized or multidisciplinary experience" (*1b*). The introductory course work can be either one or two semesters (our school utilizes a one semester experience) (*3*) followed by five (at least one semester) foundation courses in the five areas of chemistry: analytical chemistry, biochemistry, inorganic chemistry, organic chemistry and physical chemistry. This chapter will explain how our institution was inspired by the CPT to modify our existing two semester organic series into two courses that provide foundational materials for both organic and biochemistry.

The CPT also encouraged departments to develop new degree tracks or concentrations that could meet the foundation, in-depth and laboratory requirements. "Degree tracks could cover chemistry as a whole, focus on chemistry sub-disciplines such as biochemistry or polymer chemistry, or address a chemistry-related multidisciplinary area such as forensic chemistry or material science" (*1c*). Our institution had strategically hired two assistant professors (one in chemistry and one in biology) that were primarily focused in the area of biochemistry. Excitingly, the CPT guidelines now allowed us to design and implement a biochemistry track for our ACS major in addition to our pure ACS chemistry major. This new track also demonstrated that we needed to provide a foundation course for biochemistry while our curriculum would not allow for the addition of another class. This further provided incentive to revise our traditional organic series.

Discussion

One of the authors of this chapter has been a member of the committees that produced the 2006 and 2009 First Term Organic Chemistry Examinations for the Examinations Institute, Division of Chemical Education, American Chemical Society. In that experience she learned that, while the order of how we teach the first term organic series does really vary nationally, there seems to be a somewhat unified "feel" for what a first term organic class should cover. This, of course, may change in the future but for now there seems to be general acceptance of the coverage of alkanes through alcohols (with aromatics introduced in some schools) and the in-depth coverage of stereochemistry, conformational analysis, acid-base chemistry, bonding and structural theories, nomenclature, spectroscopy (IR and NMR), and mass spectrometry. These same points of interest cover the majority of the conceptual topics for a foundational organic chemistry course as listed in the Organic Chemistry Supplement (*4*) published by the Committee on Professional Training as can be seen below.

Conceptual Topics (paraphrased)

- Experimentation provided in laboratory bench setting, computational chemistry and spectroscopy
- Bonding and its consequences on molecular structure and reactivity
- Electronic, steric and orbital interactions in the behavior and properties of molecules
- Dependence of structure and reactivity on context, the environment, and phase
- Lewis and Brønsted acid-base chemistry
- Stereochemistry and conformational analysis
- Addition, elimination, substitution and rearrangement mechanisms and reactive intermediates
- Functional groups to include the centrality of carbonyl chemistry
- Organic synthesis, including retrosynthetic strategies
- Synthesis and behavior of macromolecules

The traditional outline of a normal first semester organic chemistry course covers these conceptual topics quite well with the exception of the centrality of carbonyl chemistry; however, this topic is introduced in the coverage of alcohols. As a result, we have made very little change to our coverage of material in our first semester organic course, except to introduce spectroscopy earlier in the semester and use it in the labs and lectures throughout the semester.

Based on the general acceptance of topics typically addressed in a first semester organic chemistry course, a traditional second semester organic chemistry course usually covers the remaining major functional groups including ethers, conjugated systems, aromatics (if not covered in the first semester course), carbonyls, and amines. Furthermore, a second semester organic chemistry course traditionally expands on the foundation from a first semester organic chemistry by offering advanced study of molecular orbital theory, stereoelectronics, nomenclature, spectroscopy (NMR, IR, UV-Vis), mass spectrometry, and chemical synthesis/retrosynthesis. As with a first semester organic chemistry course, these discrete topics can be taught in variable order. The laboratory experience in a second semester organic chemistry course draws upon the basic skills for chemical experimentation, synthesis, purification, and analysis and allows students to apply them in more advanced scenarios.

Much like an organic chemistry sequence, traditional biochemistry sequences can vary in length between one and three semesters. Depending on the institution, instructor background, and student constituency, a biochemistry course can be tailored to emphasize either its chemical or biological aspects; to successfully advance coverage of biochemistry beyond an introductory level, a minimum of one semester of organic chemistry is almost required to ensure students have the necessary foundation. In our experience, first semester biochemistry courses share the unifying characteristics of providing a broad foundation toward understanding 1) the four classes of biological molecules (carbohydrates, amino acids, lipids, and nucleic acids), 2) the form and function of their respective macromolecular polymers, and 3) enzymes and biological catalysis. An introductory biochemistry

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch011

course laboratory component traditionally develops the skills related to the identification, purification, and analysis of biological macromolecules and enzyme kinetics. Depending on the biochemistry course sequence, second and third semester biochemistry courses can offer in-depth study on the topics of protein structure and function (structural biochemistry), metabolic cycles and their regulation, and gene expression and replication (molecular genetics).

In their guidelines published in 2008, the CPT identified the following list of conceptual topics as appropriate for meeting the core biochemistry requirement (*5*). These conceptual topics were grouped into three general subject areas as follows:

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch011

Biological Structures and Interactions

- Fundamental building blocks (amino acids, carbohydrates, lipids, nucleotides, and prosthetic groups)
- Biopolymers (nucleic acids, peptides/proteins, glycoproteins, polysaccharides)
- Macromolecular conformations
- Membranes
- Supramolecular architecture

Biological Reactions

- Kinetics and mechanisms of biological catalysis
- Biosynthetic pathways and strategies
- Metabolic cycles and their regulation
- Organic and inorganic cofactors

Biological Equilibria and Thermodynamics

- Acid-base equilibria
- Thermodynamics of binding and recognition
- Oxidation and reduction processes
- Electron transport and bioenergetics

While the CPT acknowledges that most biochemistry foundation courses may not necessarily cover all of these topics, all should include coverage of topics from all three of the general subject areas. Furthermore, the CPT recognizes that some of these conceptual topics can be covered and, in some cases, are better suited for application in a laboratory setting; some examples that are provided include statistical analysis of data, spectroscopy, electrophoresis, chromatography, bioinformatics, molecular modeling, and isolation/identification of macromolecules.

Given the 2008 CPT criteria for the topics in foundation courses in biochemistry and organic cores, the Augustana College Department of Chemistry began the process of transitioning our traditional second semester organic chemistry course to meet the requirements of a biochemistry foundation course.

As we are guessing is the case with many currently-offered, second semester organic courses across the country, our second semester organic course has historically dabbled with introductory biochemistry topics. Most commonly, second semester organic courses cover carbohydrates, amino acids, lipids, nucleic acids, and their polymeric forms to some degree. Depending on the institution and instructor background, some even begin to discuss metabolic pathways like glycolysis/gluconeogenesis, the tricarboxylic acid (Krebs) cycle, and the biosynthesis/β-oxidation of fatty acids. In particular, the central role of these metabolic pathways and the importance/application of carbonyl chemistry (nucleophilic addition, nucleophilic acyl substitution, and enolate chemistry), carbon-carbon bond-forming reactions, and the use of protecting groups in biochemical systems make them a natural fit to elaborate on second semester organic topics. At our institution, we have modified our second semester organic curriculum to cover ethers, conjugated systems, aromatics, amines, and carbonyls in the first 8–9 weeks of a 14-week term. The remaining 6–5 weeks are dedicated to detailed discussion of biological macromolecules, polymers, and metabolic cycles.

In our experience, one of the most helpful factors in making this transition successful is the instructor's choice of textbook. Although an increasing number of undergraduate organic texts appear to include a direct and integrated application to biological systems, we have found that it is important that the text begins this process in early chapters and continues to develop this theme throughout the book. As an example, our institution has used L. G. Wade's *Organic Chemistry* as our primary organic text for several decades. While this text offers a comprehensive discussion of synthesis and spectroscopic analysis of organic compounds, we have particularly found its inclusion and application of biological chemistry to be very helpful in our course transition. A quick prevue of the various organic texts that are available will display that many of the published texts would also meet these needs including: Janice Gorzynski Smith (2nd edition), Vollhardt-Schore (5th edition), and Francis Carey (7th edition). Some texts that cover this material and also some metabolic pathways include Paula Yurkanis Bruice (5th edition) and John McMurry (5th edition). The fact that so many of these textbooks exist also emphasizes that many intstructors are already introducing biochemical topics in the foundational organic sequence and that there is a demand for texts that provide this information.

As important as the instructor's choice in textbook, we believe that it is paramount for instructors of this course to emphasize the chemical aspects of biochemistry. Although traditional organic chemistry certainly has topics that encourage memorization and terminology to a greater extent than application and problem solving, introductory biochemistry courses can be even more susceptible to this trend. As an example, the first step in glycolysis can be covered from a purely thermodynamic and conceptual angle that articulates its importance in cellular respiration. In this type of "biological" perspective, students are instructed to appreciate the big picture with minimal attention to the discrete, chemical rationale that explains ***why*** and ***where*** a biochemical reaction takes place; little (if any) emphasis is placed on understanding how hexokinase phosphosphorylates the only primary hydroxyl in glucose, which also happens to be its most reactive nucleophile. In contrast, a chemical approach to instructing biochemistry will

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch011

draw heavily upon organic chemistry theory and emphasize the structural aspects of biomolecules and biochemical transformations. This approach also promotes our goal of transforming a second semester organic chemistry into a biochemistry foundation course by providing applications and adaptations of organic chemistry in biological systems. By learning the related organic chemistry first, parallels can, and should, be drawn to biochemical systems; as an example, the physiological equivalent of methyl iodide is S-adenosylmethionine (SAM) and the biochemical version of $LiAlH_4$ is NAD(P)H.

At our institution, we try to construct the laboratory portions of chemistry courses in such a way that they parallel and provide practical application of the topics discussed in lecture. With our first semester organic course, this is more difficult to accomplish given the necessary introduction of several "new" laboratory skills, the related theory (e.g. extraction, distillation, crystallization, spectroscopy, among others), and the limited knowledge of applicable functional groups at the start of the course. In our second semester course, we have allocated approximately 40% of the laboratory periods to dedicated experiments that utilize chemical methods to analyze biochemical systems. These labs explore carbohydrates (kinetic/thermodynamic control, the anomeric effect, polarimetry, and ^1H NMR analysis of diasteromeric mixtures), amino acids (dipeptide sequencing, various forms of chromatography), lipids (transesterification of triacylglycerols, analysis of unsaturation via ^1H NMR), and acid-base biochemistry (titration, Henderson–Hasselbalch, zwitterions).

Assessment for this course design has been based heavily on the performance of students on standardized Organic Exams through the ACS Division of Chemical Education - Examinations Institute and end of course student evaluations. We have utilized the ACS First Term Organic Chemistry Exams as the final for our first semester organic course since the 2006 exam was made available. Our student scores have been fairly steady with a slightly higher than national average of 52 percentile. The second semester course relies upon two tests to assess the student learning. We use the Second Term Organic Chemistry Exam as the class final along with an internally written biochemistry exam for our hybrid second semester organic/biochemistry course. Our students are also fairly steady with a slightly higher than national average of 64 percentile on the ACS full organic sequence. The ACS Exam Institute Biochemistry Exam (an exam written for a two semester biochemistry course) is administered as a midterm exam in our *in-depth* one semester biochemistry course (that all of our chemistry and biochemistry majors are required to take), medicinal chemistry.

As in the case with many chemistry departments, a large proportion of our organic students are interested in health related fields. The student comments have been overwhelmingly positive since we made these changes. Interestingly, we have also seen an increase in the total number of chemistry and biochemistry majors since the curriculum change. Thus, overall student learning has remained consistent on the standardized ACS organic final even with the intentional emphasis on biochemical topics and student perceptions of the course as an "excellent" course have increased. Student comments seem to center on the themes that inclusion of biochemical application makes the course more interesting when they can see the material "cross" the boundaries between the

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch011

disciplines and that the chemistry is central to what is going on. They also seem to get excited that they can understand the chemical context rather than memorizing a box where products are magically produced by an enzyme.

Conclusions

We have remodeled our traditional two semester organic series to correspond with courses that would match the foundational courses for both organic and biochemistry. We had to make slight changes in our first semester course with major modifications in the second semester course, allocating approximately 40% of the lecture and lab to biochemical topics. Overall, these changes were not hard to implement and many of the standard organic textbooks support these changes. Our student learning outcome for the organic material has remained consistent throughout the transition period, even with the additional biochemical content. Overall student perceptions of our changes have been very positive. Thus, from an instructors' point of view, we have seen that the emphasis on biochemical topics have made the organic chemistry more relevant to a wider population of our students.

Acknowledgments

The authors would like to thank Augustana College and the Department of Chemistry for its support of this work.

References

1. Polik, W. F.; Larive, C. K. New ACS Guidelines Approved by CPT. *J. Chem. Educ.* **2008**, *85*, 484–487 (1b p. 484, 1c p. 485).
2. The steering committee of MPPG is made up of 12 members: three committee representatives (DAC, M&E, and Comsci), representatives of the 5 divisions who contribute the most programming to ACS national meetings, and 4 elected representatives from divisions.
3. Our department has needed to create a second semester general chemistry course in our interim due to the high demand in our pre-health programs and some medical schools requiring a second semester general chemistry option.
4. http://www.acs.org/cpt.
5. http://portal.acs.org/portal/PublicWebSite/about/governance/committees/training/acsapproved/degreeprogram/CTP_005583.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch011

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

Chapter 12

Enabling 21st Century Student Success in Undergraduate Organic Chemistry

**David P. Pursell,* Joseph C. Sloop, Richard L. Pennington,
Julia B. Paredes, Mai Yin Tsoi, and Sonal Dekhane**

**School of Science & Technology, Georgia Gwinnett College, Lawrenceville,
GA 30043, USA
*dpursell@ggc.edu**

Organic chemistry instructors at a newly founded four-year college have integrated 21st century handheld technology and applications into the organic chemistry class and lab experience, in an effort to further engage students and increase content and skill mastery. The technology and applications enable instructors to implement a philosophy of teaching and learning known as the Thayer method. In this method, students prepare before class and lab; their preparation is supported by a detailed course syllabus and materials available in multiple media formats - textbooks, e-books, videos, electronic flashcards, and content applications (apps) - all of which are easily accessible via computers and mobile devices. Because students come to class and lab already familiar with the fundamentals of the concepts to be covered, the instructor is free to focus specifically on topics and problems as dictated by the students. This helps maximize the efficiency and engagement of the student-instructor contact time, and allows the students to become active participants, rather than passive observers, in the class. In this way, the substantial improvement in student preparation before class and lab (the underlying premise of the Thayer method) goes hand in hand with the improvement of student comprehension and mastery of the material. Student and faculty response to this novel 21st century approach to undergraduate organic chemistry has been overwhelmingly positive, and research efforts are ongoing to determine impact

In Advances in Teaching Organic Chemistry; Duffy-Matzner, J., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2012.

on student learning. An early result is that over 90% of students successfully complete the two-semester organic chemistry class and lab sequence.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

The STEM Education Challenge

It is well known that STEM disciplines are challenging for undergraduates - and as a result, many undergraduates avoid these disciplines. Many others who enter STEM majors change to non-STEM majors before graduation. At the same time, it is rare that undergraduates outside of STEM disciplines change their plans and become STEM majors (*1*). In response to this trend, President Obama has called on colleges to graduate 10,000 more engineers a year and 100,000 more teachers with majors in STEM (*2*). While there may be some gains in getting K-12 students excited about STEM fields, the excitement wanes as undergraduates confront what David E. Goldberg, emeritus professor at the University of Illinois, calls “the math-science death march” of calculus, physics and chemistry in lecture halls with hundreds of other students (*3*). The President’s Council of Advisors on Science and Technology asks colleges and universities to transform STEM education, as mounting evidence suggests that significant numbers of those who enter college inclined to study math and science abandon those plans within the first two years. These students often cite uninspiring introductory courses and “unwelcoming” environments as causes for this shift in their career goals (*4*).

If there is to be a transformation of undergraduate STEM education, it ought not be a transformation that lowers standards in an attempt to make STEM more “student friendly.” However, the notion of making STEM more “student friendly” through other means is not without merit. The majority of today’s undergraduate students were born between 1978 and 1995. Termed the “millennials” or “generation Y”, these students are product consumers; their lives are heavily influenced by technology, social media, and connectivity (*5*). Today’s students interact with the world quite differently from how many of their professors did when they were students - a world based on books and chalkboards rather than touchscreen phones and wi-fi enabled tablet computers. Thus, it follows that perhaps in order to improve the “student-friendly” aspect of STEM majors, educators should tap into the tools and resources that these millenials incorporate into their daily lives - computers and mobile devices. This philosophy is quite a divergence from traditional methods of teaching and learning, which focus on a teacher-centered classroom and minimal resources to support student interactions with the course content.

While there has been a transformation in the use of educational technology in recent years, David Parry of the University of Texas at Dallas has written that “…just as [educators] have introduced computers into the classroom and as we have started to come to terms with the idea of wired learning spaces, mediated laptops, and occasional dinosaur-like desktops - the mobile web is about to make all this technological adaptation rather outdated, as the learning space is about to substantially alter the landscape of teaching with and through technology” (*6*).

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

Maintaining pace with changes in educational technology is a resource intensive endeavor. Moreover, it is difficult to gauge whether educational technology actually enables student learning. In particular, the current generation of students is one of media multi-tasking. Researchers have shown that heavy media multi-taskers are more susceptible to interference from irrelevant environmental stimuli, leading to poorer performance in task-switching ability as compared to light media multi-taskers (*7*). Michael Wesch, anthropology professor at Kansas State University, has written that one can teach well with technology. But while teaching with interactive tools replacing the lecture appears to be gaining widespread acceptance, he notes that "it doesn't matter what method you use if you do not first focus on one intangible factor: the bond between professor and student" (*8*).

At a time when once again there is an increased focus on STEM education, the University system of Georgia (USG) created a new college with a charter to "do things differently." Georgia Gwinnett College (GGC) opened in Fall 2006 as the first new four-year public college created in Georgia in more than a hundred years and the first new four-year public college created in the nation in the 21st century. The college admitted its first class of juniors in August 2006, its first freshman class in August 2007, earned full SACS accreditation in 2009, and has 8500 students in spring 2012. GGC is an open access (non-competitive admissions) public college, one of only two within the University System of Georgia that serves northeast Georgia. Its student population reflects the diversity of Gwinnett County, the 9th fastest growing county in the U.S. and the 2nd most populous in Georgia. The GGC Vision is to be a college . . .

> *"where learning will take place continuously in and beyond the confines of the traditional classroom. Its cornerstones will be innovative use of educational technology and a commitment to an integrated educational experience that develops the whole person. GGC will be a wellspring of educational innovation. It will be a dynamic learning community where faculty engagement in teaching and mentoring students will be the hallmark. It will be a driving force for change in student success. As such, it will be a model for innovative approaches to education, faculty engagement with students, and highly efficient student, facility, and administrative services." (9)*

While innovative use of educational technology is part of the aforementioned vision, President Daniel Kaufman has often stated that "it's not about the gizmo (holding a smart phone up for a group of newly hired faculty to see), it's about using the gizmo to enhance student learning" (*10*).

The Organic Chemistry Education Challenge

What makes organic chemistry a special challenge for students and faculty? It is typically a sophomore level, two-semester course sequence including laboratory

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

and is a gateway course for upper level biology, biochemistry, and chemistry programs. In addition, it is required of virtually all students pursuing medical, dental, pharmaceutical or other health professional schools and training. As such, it is populated with students of broad academic and professional interests. Most students find the course exceptionally challenging because of the breadth and depth of content, the rapid pace of the course, and the notion that each successive lesson directly builds on previous lessons over the entire year-long sequence. In fact, students know organic chemistry as “the infamous, dreaded ‘orgo’, a marathon of memorization” (*11*). Such sentiment is common among students about to begin undergraduate organic chemistry, as at most schools between 25-50% of students do not continue to the second semester.

Unfortunately, the negative perception of organic chemistry is quite widespread and, to some degree, contributes to the continuing decrease of STEM students. A recent Journal of Chemical Education editorial by Norbert Pienta noted that a Pharm.D. student technician, who had taken Pienta’s organic chemistry course, said “you don’t have to tell me who you are. You are the reason I almost didn’t get into pharmacy school” (*12*). Here again, organic chemistry is specifically represented as an obstacle for students to overcome. Marlene Katz, of the Saint Louis College of Pharmacy, finds that many students believe the obstacle of organic chemistry can be best overcome by obtaining old exams, relentless memorization, and selection of the “easiest” professor (*13*). “As long as we have pre-med students, we’ll have organic chemistry” states Steven David, Johns Hopkins Vice Dean for Undergraduate Education, “…the question is how to make it better”. David adds that at Johns Hopkins, the goal is to reform classes “in a way that allows more students to be successful, and slow the flow of science majors to humanities majors (*14*)”. To address this goal, researchers have tried to isolate the factors that contribute to student success in organic chemistry, and have found that prior math and chemistry knowledge and skills are not necessarily indicative of success in organic chemistry, but what is a good indicator of this success is a positive attitude toward the study of chemistry (*15*).

In her 2007 James Flack Norris Award address, chemistry professor Diane Bunce of The Catholic University of America wrote that when students don’t perform well, faculty usually believe that it is the students who are at fault, and rarely consider if they, as faculty members, have appropriately structured the course to align with students’ levels of ability and understanding. She identifies four major challenges to student success: 1) lecture (too much information to absorb); 2) study time (college life is “24/7” but faculty members are typically “9-5”); 3) communication (mostly one-way from faculty to student); 4) ownership of the course (the course “belongs” to faculty, and students are “consumers” in their education). Bunce concludes that creating a learning environment that is a community of learners with shared responsibility (rather than a learning environment that is teacher-driven) offers the best opportunity for student learning (*16*). Thus, by changing the classroom culture in which student learning occurs, we may be able to directly impact student attitudes towards learning organic chemistry, which in turn may give rise to augmented student success in the course.

Organic Chemistry at GGC

What comes first - technology and then figuring out a way to use it in education, or determining a need or requirement in education and then employing technology to support this need? This is a question many faculty ask themselves as the rapid pace of change of educational technology often results in college administrators "mandating" faculty use of these tools in their courses to increase student learning, even when it is not clear how the technology will actually help the students learn. Whether educational technology is a panacea for lack of student learning, or rather, an enabling tool for the core "work" of learning, is a topic of much discussion. Our approach to organic chemistry at GGC is foremost to maintain recognized academic standards of what organic chemistry students should know and be able to do in both class and lab settings. As a new college, we have developed a program from "whole cloth," beginning in 2007, that is designed to address the many educational issues noted earlier in this chapter, especially the four points highlighted by Professor Bunce.

Perhaps the most important aspect of our program is small section size. Dr. Thomas Mundie, Dean of the School of Science and Technology at GGC, has supported an outcomes-based, integrated organic course sequence in which the same instructor and a maximum of 24 students negotiate the class and lab experience together. For a large (and growing) public college, this 24 student section size is unusual, and key to our successful use of the Thayer method of teaching and learning. It is through the incorporation of the Thayer method into our classroom philosophy and teaching practices to meet the 21st century learning environment, that we are able to achieve a 90% student success rate in completion of the 2-semester organic chemistry sequence.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

The Thayer Method

There has been much research on pedagogical approaches to teaching a demanding, rigorous course such as organic chemistry. Often the introductory organic chemistry course is a large lecture course with separate recitation sections and a separate laboratory course. Such pedagogy has limitations, and educators have experimented with many alternative approaches, such as active and cooperative learning, student directed and team learning, grade-study contacts, problem-solving and collaborative-learning, distance-education, and meta tasks for organizing knowledge. These studies indicate that there is enhanced learning and greater student satisfaction when the traditional lecture course is supplemented with other instructional techniques (*17–32*).

As long as class size is relatively small, one approach that enhances student engagement is the Thayer Method, named for Sylvanus Thayer, the Superintendent of the United States Military Academy at West Point, from 1817-1833. Thayer was a class of 1807 Dartmouth College alum, who after his West Point experience, subsequently initiated what became the Dartmouth engineering program. At West Point, Thayer increased academic rigor and made the focus of the academic program to train civil engineers for the growing nation. The Thayer Method defines teaching as supporting student learning. Similar

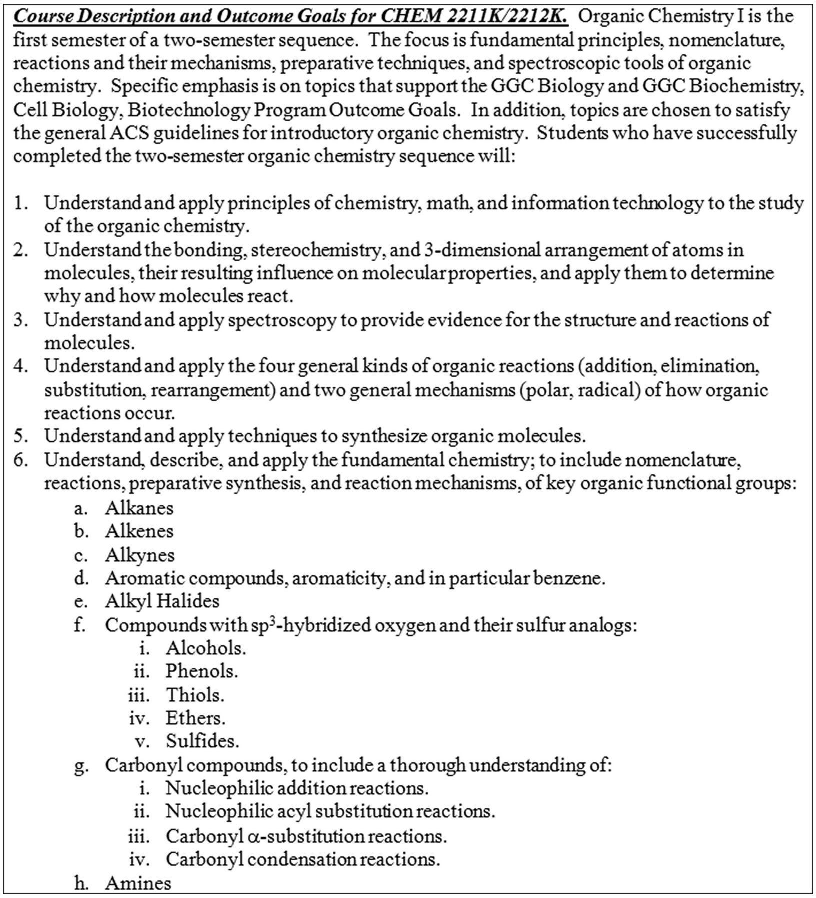
Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

to what is currently referred as "learning forward" or "flipping," the Method's hallmark is that *students prepare prior to class*, so each lesson is published in advance with student lesson objectives, study assignment, terms, concepts, and homework problems. After preparing, students meet with the professor and their peers during class and "recite" what they have learned, which inspires more critical discussion and application through more advanced problem solving. The tenets of the Thayer Method are highlighted below.

- Students are responsible for their learning, which is incremental and sequential.
- Students prepare before class/lab guided by a detailed syllabus and a variety of course resources.
- Small class sizes, facilitating efficient student-instructor and student-student interaction, discussion and reflection.
- Instructor facilitates student learning before, during, and after class/lab.
- Minimize lecture, maximize active, student-directed, collaborative learning.
- Students demonstrate their knowledge of the material through in-class board work, demonstrating problem solving in an attempt to initiate student ownership and responsibility for their learning.
- Students are asked to demonstrate mastery in a formal process by "publishing" and defending (reciting) their understanding of the course content to their peers Frequent assessment and feedback, supporting mastery of course material and allowing students to know where they stand at any point during the semester.

With the Thayer Method, there is essentially a contract whereby students commit to preparing before class and instructors commit to flexibility in facilitating student learning during class by allowing sufficient time for discussion, exploration of more challenging topics in depth, and student recitation under the guiding and mentoring eye of the instructor (typically via student problem solving whiteboard sessions) (*33–35*). Students may also be called on to defend their method of solving the problem to their peers, thus attempting to increase student communication and critical thinking skills.

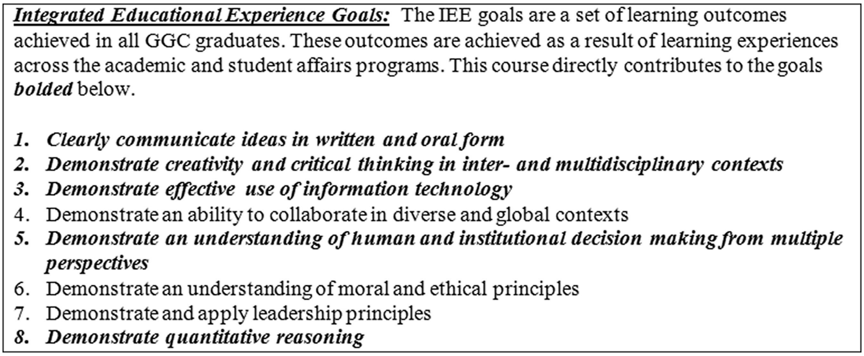
Before the first meeting of the semester, instructors provide a detailed syllabus with lesson assignments for the entire semester. All of the course materials are posted on the course management system, which for the last few years at GGC has been BlackBoard©. The syllabus includes the course outcome goals for the entire two-semester sequence of class and lab, so that students can maintain perspective of the big picture of the course rather than a myopic view of the details of each lesson. The course outcome goals (Figure 1) are directly linked to the GGC Integrated Educational Experience (IEE) Goals (Figure 2) for all GGC students. Taught using the Thayer Method, the organic chemistry course develops students in five of the eight IEE goals. In addition to outcome goals, the syllabus also details who, what, when, and how of each graded event. Our class meetings (lessons) are for 1 hour and 15 minutes, so there are 30 lessons per semester and 15 laboratory periods of 2 hours and 45 minutes each, which typically results in two class meetings and one lab meeting per week.



Course Description and Outcome Goals for CHEM 2211K/2212K. Organic Chemistry I is the first semester of a two-semester sequence. The focus is fundamental principles, nomenclature, reactions and their mechanisms, preparative techniques, and spectroscopic tools of organic chemistry. Specific emphasis is on topics that support the GGC Biology and GGC Biochemistry, Cell Biology, Biotechnology Program Outcome Goals. In addition, topics are chosen to satisfy the general ACS guidelines for introductory organic chemistry. Students who have successfully completed the two-semester organic chemistry sequence will:

1. Understand and apply principles of chemistry, math, and information technology to the study of the organic chemistry.
2. Understand the bonding, stereochemistry, and 3-dimensional arrangement of atoms in molecules, their resulting influence on molecular properties, and apply them to determine why and how molecules react.
3. Understand and apply spectroscopy to provide evidence for the structure and reactions of molecules.
4. Understand and apply the four general kinds of organic reactions (addition, elimination, substitution, rearrangement) and two general mechanisms (polar, radical) of how organic reactions occur.
5. Understand and apply techniques to synthesize organic molecules.
6. Understand, describe, and apply the fundamental chemistry; to include nomenclature, reactions, preparative synthesis, and reaction mechanisms, of key organic functional groups:
    a. Alkanes
    b. Alkenes
    c. Alkynes
    d. Aromatic compounds, aromaticity, and in particular benzene.
    e. Alkyl Halides
    f. Compounds with sp^3-hybridized oxygen and their sulfur analogs:
        i. Alcohols.
        ii. Phenols.
        iii. Thiols.
        iv. Ethers.
        v. Sulfides.
    g. Carbonyl compounds, to include a thorough understanding of:
        i. Nucleophilic addition reactions.
        ii. Nucleophilic acyl substitution reactions.
        iii. Carbonyl α-substitution reactions.
        iv. Carbonyl condensation reactions.
    h. Amines

Figure 1. Excerpt of Course Outcome Goals.



Integrated Educational Experience Goals: The IEE goals are a set of learning outcomes achieved in all GGC graduates. These outcomes are achieved as a result of learning experiences across the academic and student affairs programs. This course directly contributes to the goals ***bolded*** below.

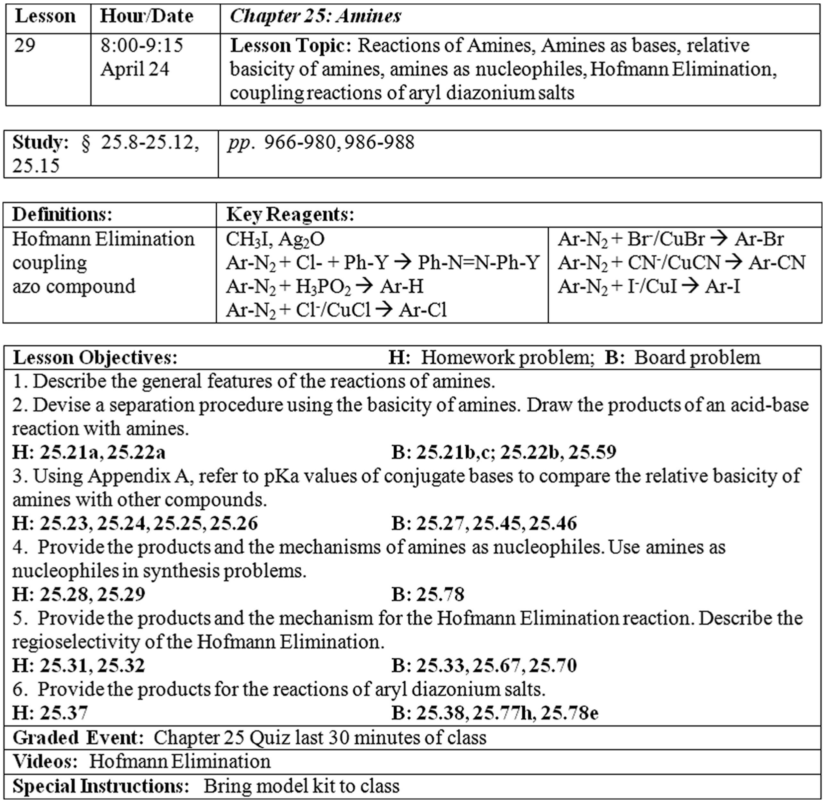
1. ***Clearly communicate ideas in written and oral form***
2. ***Demonstrate creativity and critical thinking in inter- and multidisciplinary contexts***
3. ***Demonstrate effective use of information technology***
4. Demonstrate an ability to collaborate in diverse and global contexts
5. ***Demonstrate an understanding of human and institutional decision making from multiple perspectives***
6. Demonstrate an understanding of moral and ethical principles
7. Demonstrate and apply leadership principles
8. ***Demonstrate quantitative reasoning***

Figure 2. GGC Integrated Educational Experience (IEE) Goals.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

Each lesson has an accompanying daily lesson sheet (Figure 3) that provides the specific assignments that students must complete prior to class and lab. The sheet lists the lesson topics, study/read/scan assignments, definitions, specific lesson objectives and homework problems aligned with each objective, in-class board problems for each objective, graded event details, supplemental study information and instructions. Graded events (Figure 4) are aligned with the course outcome goals and instructors track results over the course of the semester. Each problem on graded events (Figure 5) specifically aligns with course outcome goals so that students are continually reminded how various topics contribute to the big picture of the course. The end result is that students know exactly what is expected of them for the entire semester and in return, faculty expect students to prepare prior to class/lab meetings in order to enable the efficiency and effectiveness of the professor-student face-to-face time in class and lab. In other words, sophomore level students are sophisticated and resourceful enough to learn the basic material through the available course materials (textbook, ebook, text solutions manual, flashcards, podcasts, TsoiChem app, laboratory techniques videos, on-line homework, etc) we make available as discussed in the next section.



Lesson	**Hour/Date**	***Chapter 25: Amines***
29	8:00-9:15 April 24	**Lesson Topic:** Reactions of Amines, Amines as bases, relative basicity of amines, amines as nucleophiles, Hofmann Elimination, coupling reactions of aryl diazonium salts

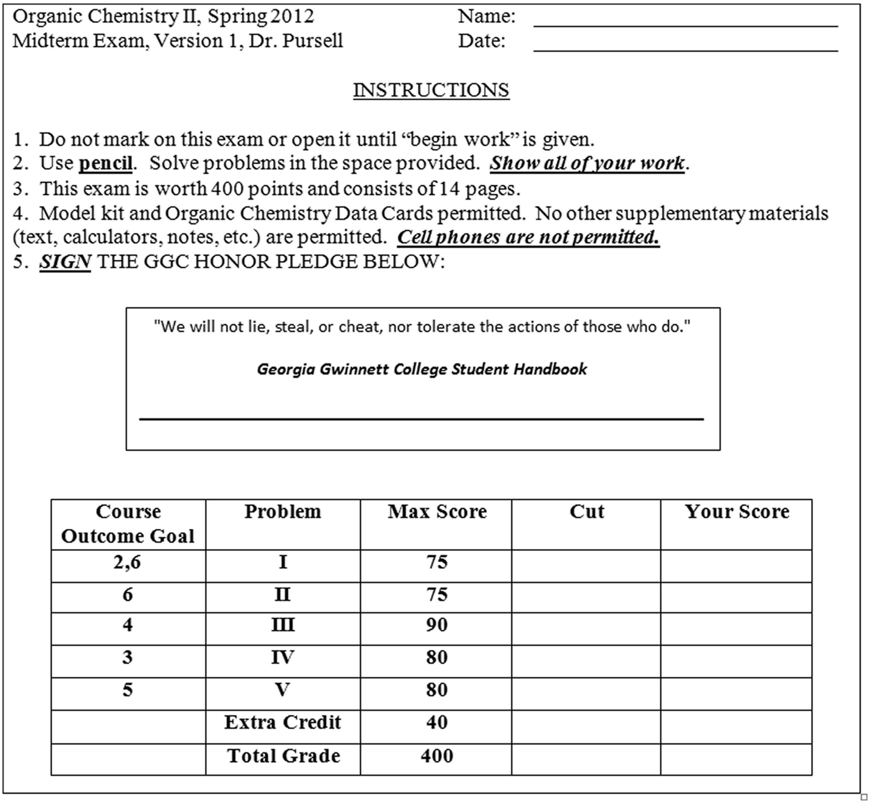
Study: § 25.8-25.12, 25.15	*pp.* 966-980, 986-988

Definitions:	**Key Reagents:**	
Hofmann Elimination coupling azo compound	CH_3I, Ag_2O $Ar\text{-}N_2 + Cl\text{-} + Ph\text{-}Y \rightarrow Ph\text{-}N{=}N\text{-}Ph\text{-}Y$ $Ar\text{-}N_2 + H_3PO_2 \rightarrow Ar\text{-}H$ $Ar\text{-}N_2 + Cl^-/CuCl \rightarrow Ar\text{-}Cl$	$Ar\text{-}N_2 + Br^-/CuBr \rightarrow Ar\text{-}Br$ $Ar\text{-}N_2 + CN^-/CuCN \rightarrow Ar\text{-}CN$ $Ar\text{-}N_2 + I^-/CuI \rightarrow Ar\text{-}I$

Lesson Objectives:	**H:** Homework problem; **B:** Board problem
1. Describe the general features of the reactions of amines.	
2. Devise a separation procedure using the basicity of amines. Draw the products of an acid-base reaction with amines.	
H: 25.21a, 25.22a	**B: 25.21b,c; 25.22b, 25.59**
3. Using Appendix A, refer to pKa values of conjugate bases to compare the relative basicity of amines with other compounds.	
H: 25.23, 25.24, 25.25, 25.26	**B: 25.27, 25.45, 25.46**
4. Provide the products and the mechanisms of amines as nucleophiles. Use amines as nucleophiles in synthesis problems.	
H: 25.28, 25.29	**B: 25.78**
5. Provide the products and the mechanism for the Hofmann Elimination reaction. Describe the regioselectivity of the Hofmann Elimination.	
H: 25.31, 25.32	**B: 25.33, 25.67, 25.70**
6. Provide the products for the reactions of aryl diazonium salts.	
H: 25.37	**B: 25.38, 25.77h, 25.78e**
Graded Event: Chapter 25 Quiz last 30 minutes of class	
Videos: Hofmann Elimination	
Special Instructions: Bring model kit to class	

Figure 3. Sample Daily Lesson Sheet.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012



Organic Chemistry II, Spring 2012 Name: ______________________________
Midterm Exam, Version 1, Dr. Pursell Date: ______________________________

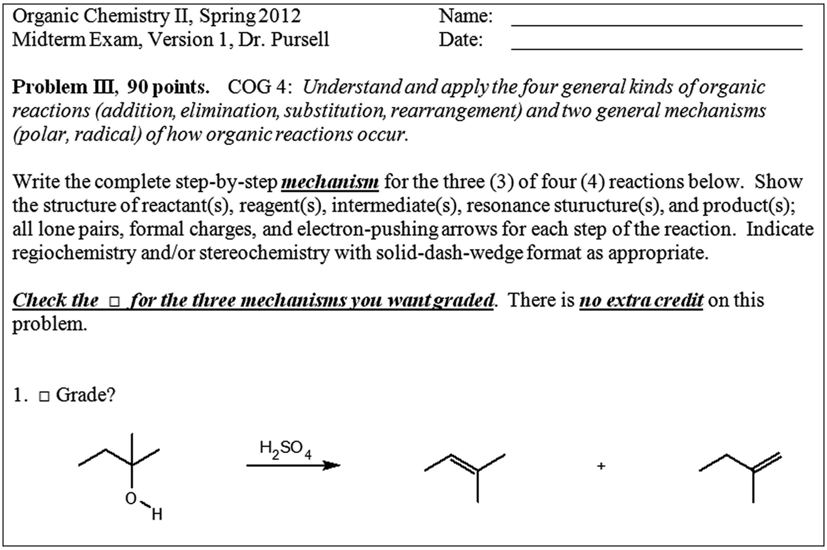
INSTRUCTIONS

1. Do not mark on this exam or open it until "begin work" is given.
2. Use **pencil**. Solve problems in the space provided. ***Show all of your work***.
3. This exam is worth 400 points and consists of 14 pages.
4. Model kit and Organic Chemistry Data Cards permitted. No other supplementary materials (text, calculators, notes, etc.) are permitted. ***Cell phones are not permitted.***
5. ***SIGN*** THE GGC HONOR PLEDGE BELOW:

> "We will not lie, steal, or cheat, nor tolerate the actions of those who do."
>
> ***Georgia Gwinnett College Student Handbook***
>
> ____

Course Outcome Goal	Problem	Max Score	Cut	Your Score
2,6	I	75		
6	II	75		
4	III	90		
3	IV	80		
5	V	80		
	Extra Credit	40		
	Total Grade	400		

Figure 4. Sample exam cover sheet tracking student performance per Course Outcome Goal.



Organic Chemistry II, Spring 2012 Name: ______________________________
Midterm Exam, Version 1, Dr. Pursell Date: ______________________________

Problem III, 90 points. COG 4: *Understand and apply the four general kinds of organic reactions (addition, elimination, substitution, rearrangement) and two general mechanisms (polar, radical) of how organic reactions occur.*

Write the complete step-by-step ***mechanism*** for the three (3) of four (4) reactions below. Show the structure of reactant(s), reagent(s), intermediate(s), resonance suructure(s), and product(s); all lone pairs, formal charges, and electron-pushing arrows for each step of the reaction. Indicate regiochemistry and/or stereochemistry with solid-dash-wedge format as appropriate.

Check the ☐ for the three mechanisms you want graded. There is ***no extra credit*** on this problem.

1. ☐ Grade?

Figure 5. Sample exam problem aligned with Course Outcome Goal.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

Four Challenges

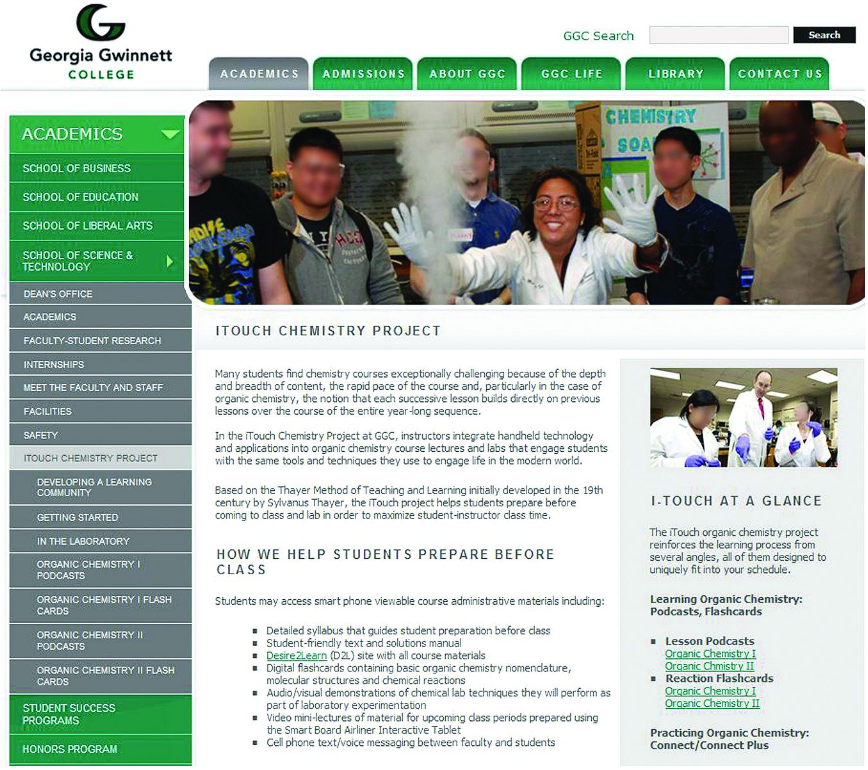
Before outlining the resources we have developed for the course, it is useful to return to Bunce's four challenges to student success: lecture, study time, communication, ownership. First, by completing their homework assignment prior to class, students know both (a) what they are able to understand and do, as well as (b) what they do not understand and cannot do. Therefore, students set the agenda for the professor-student face-to-face time as the instructor does not lecture, but responds to discussion and questions initiated by students. The challenge for the professor during these discussion sections is to weave the many student questions into a big picture view of how the particulars of the lesson fit into previous lesson topics and how the lesson leads to lesson topics yet to come. Perhaps half of the class meeting is discussion driven by students.

The second half of the class period is problem solving at the white boards. The board problems are typically more challenging than the assigned homework problems and enable students to solidify conceptual understanding and application. Students work individually or in groups, with the instructor giving hints and suggestions as needed, to keep students moving forward. Once several students have solved a problem, the professor typically stops all students and calls on a student, or group of students, to explain how they solved the problem. The students present and defend their approach to their classmates. Classmates ask questions. Students learn from each other. The professor keeps the interaction factually correct and helps students make connections to the big picture of organic chemistry. Often students develop alternative solutions, especially in synthesis, so the board sessions present many opportunities for students to present to each other various ways to solve problems.

By the end of the class period students know exactly where they stand in terms of the lesson's objectives - either they understand and can work the problems, or they do not understand and cannot do so, and need to schedule additional time with the professor. Likewise for the professor, who on a daily basis knows which students are doing well and which are falling behind, intervention can come early, rather than after the "midterm" exam. In Thayer's terms, the lessons and class periods are discrete, incremental, collaborative, interactive, and sequential – and the minimization of lecture addresses Bunce's first challenge.

The second challenge is that study time occurs when students interact with the course material, not when the professor holds working hours during the day. At GGC, our organic chemistry course is set up with resources accessible 24/7 via the GGC public web page (Figure 6) and Blackboard course management system (Figure 7). Thus, students are able to access these resources - whether a podcast mini-lecture, a set of electronic flashcards, or a laboratory technique video - no matter where the student is or the time of day. In addition, GGC provides every faculty member a smart phone for outside of class student engagement. Most instructors respond to student text messages quickly, typically within a few minutes, up to a designated evening time. In this way, the GGC organic course resources and faculty are accessible to students well beyond "normal" office hours, and this illustrates an example of our use of technology to promote a learning environment that meets the needs of the 21st century student.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012


Georgia Gwinnett College
GGC Search
Search
ACADEMICS
ADMISSIONS
ABOUT GGC
GGC LIFE
LIBRARY
CONTACT US
ACADEMICS
SCHOOL OF BUSINESS
SCHOOL OF EDUCATION
SCHOOL OF LIBERAL ARTS
SCHOOL OF SCIENCE & TECHNOLOGY
DEAN'S OFFICE
ACADEMICS
FACULTY-STUDENT RESEARCH
INTERNSHIPS
MEET THE FACULTY AND STAFF
FACILITIES
SAFETY
ITOUCH CHEMISTRY PROJECT
DEVELOPING A LEARNING COMMUNITY
GETTING STARTED
IN THE LABORATORY
ORGANIC CHEMISTRY I PODCASTS
ORGANIC CHEMISTRY I FLASH CARDS
ORGANIC CHEMISTRY II PODCASTS
ORGANIC CHEMISTRY II FLASH CARDS
STUDENT SUCCESS PROGRAMS
HONORS PROGRAM
CHEMISTRY
SOAP

ITOUCH CHEMISTRY PROJECT

Many students find chemistry courses exceptionally challenging because of the depth and breadth of content, the rapid pace of the course and, particularly in the case of organic chemistry, the notion that each successive lesson builds directly on previous lessons over the course of the entire year-long sequence.

In the iTouch Chemistry Project at GGC, instructors integrate handheld technology and applications into organic chemistry course lectures and labs that engage students with the same tools and techniques they use to engage life in the modern world.

Based on the Thayer Method of Teaching and Learning initially developed in the 19th century by Sylvanus Thayer, the iTouch project helps students prepare before coming to class and lab in order to maximize student-instructor class time.

HOW WE HELP STUDENTS PREPARE BEFORE CLASS

Students may access smart phone viewable course administrative materials including:

- Detailed syllabus that guides student preparation before class
- Student-friendly text and solutions manual
- Desire2Learn (D2L) site with all course materials
- Digital flashcards containing basic organic chemistry nomenclature, molecular structures and chemical reactions
- Audio/visual demonstrations of chemical lab techniques they will perform as part of laboratory experimentation
- Video mini-lectures of material for upcoming class periods prepared using the Smart Board Airliner Interactive Tablet
- Cell phone text/voice messaging between faculty and students

I-TOUCH AT A GLANCE

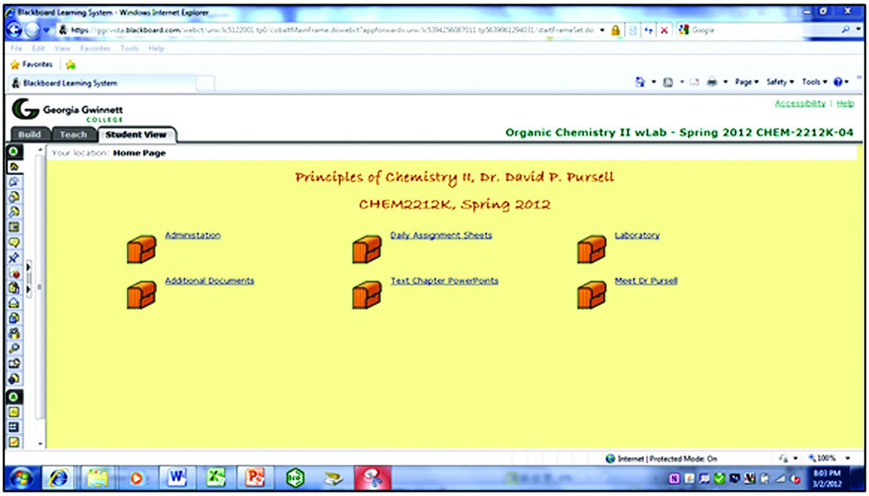
The iTouch organic chemistry project reinforces the learning process from several angles, all of them designed to uniquely fit into your schedule.

Learning Organic Chemistry: Podcasts, Flashcards

- **Lesson Podcasts**
  Organic Chemistry I
  Organic Chmistry II
- **Reaction Flashcards**
  Organic Chemistry I
  Organic Chemistry II

Practicing Organic Chemistry: Connect/Connect Plus

Figure 6. Screen shot of the public web page for the organic course media materials. (Reproduced with permission)


Blackboard Learning System - Windows Internet Explorer
File Edit View Favorites Tools Help
Favorites
Blackboard Learning System
Page Safety Tools
Georgia Gwinnett College
Accessibility | Help
Build
Teach
Student View
Your location: Home Page
Administation
Daily Assignment Sheets
Laboratory
Additional Documents
Text Chapter PowerPoints
Meet Dr Pursell
Internet | Protected Mode: On
100%
8:03 PM
3/2/2012

Organic Chemistry II wLab - Spring 2012 CHEM-2212K-04

Principles of Chemistry II, Dr. David P. Pursell

CHEM2212K, Spring 2012

Figure 7. Screen shot of a sample Blackboard course management web page.

Third, communication in the GGC organic chemistry course is a two-way, back and forth process between the professor and the students. Before the semester begins, a professor initiates communication to the students in the form of course materials. After the issuance of course materials, however, the direction of communications is mainly from the students to the professor. The culture is one where students believe faculty facilitate student learning, but the work of student learning belongs to students. Ensuring that the communication is two-way and student centered, we have addressed Bunce's third challenge to student success.

This leads to Bunce's fourth challenge - ownership of the course. Faculty have laid out in great detail what organic chemistry students must understand and be able to do and have set up learning conditions for students to be successful. Students know by the end of each meeting exactly what they can and cannot do in the course. They own their progress and their success with organic chemistry while recognizing that their professor is their coach, guide, and mentor. However, for many students, an approach such as the Thayer Method is a new and intimidating kind of learning experience. Many students are accustomed to sitting through a traditional lecture, and then trying to figure out the lecture material at some later, undetermined time and place. We have found that within a few meetings most students adapt to the Thayer Method as long as professors do not waver when the inevitable student resistance to the change in philosophy is encountered early in the semester. Without wavering, our experience has been that virtually all of the students with similar questions become stakeholders of the Thayer Method within a few lessons, removing Bunce's fourth obstacle to student success.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

Enabling the Thayer Method for the 21st Century

Before the first meeting of the semester, instructors provide a detailed syllabus with lesson assignments for the entire semester via the public web and course management system. The pre-class and pre-lab study requirement may at first seem daunting to students. We therefore decided to leverage the one piece of equipment that almost every 21st century student is never without - the mobile device (cellphone). Given its relatively low cost, its shallow learning curve, and the students' incorporation of the device into their everyday life, the handheld mobile device surfaced as the learning tool to exploit in 21st century education. However, educational technology is only as effective as the ways in which it is used. In our project, we purposefully and carefully analyzed the areas in which mobile technology could best support and enable student success while using the Thayer method of teaching and learning. Upon making those fundamental determinations, we designed and developed a suite of resources and materials accessible and viewable on mobile devices (as well as via computers). All of these materials are accessible through the GGC public web page, wiki site, and Blackboard course management site. The suite of materials includes:

- Mini-lecture "podcasts" with audio voice-over, created and recorded by GGC chemistry faculty.

- Innovative organic chemistry mobile applications (apps) developed through a collaboration of GGC organic chemistry and information technology faculty and students.
- Organic chemistry functional group and reaction flashcards for use with student "drills."
- High-definition lab technique videos featuring GGC organic faculty.
- Online homework system with guided feedback and directed readings.
- GGC organic chemistry Facebook groups.

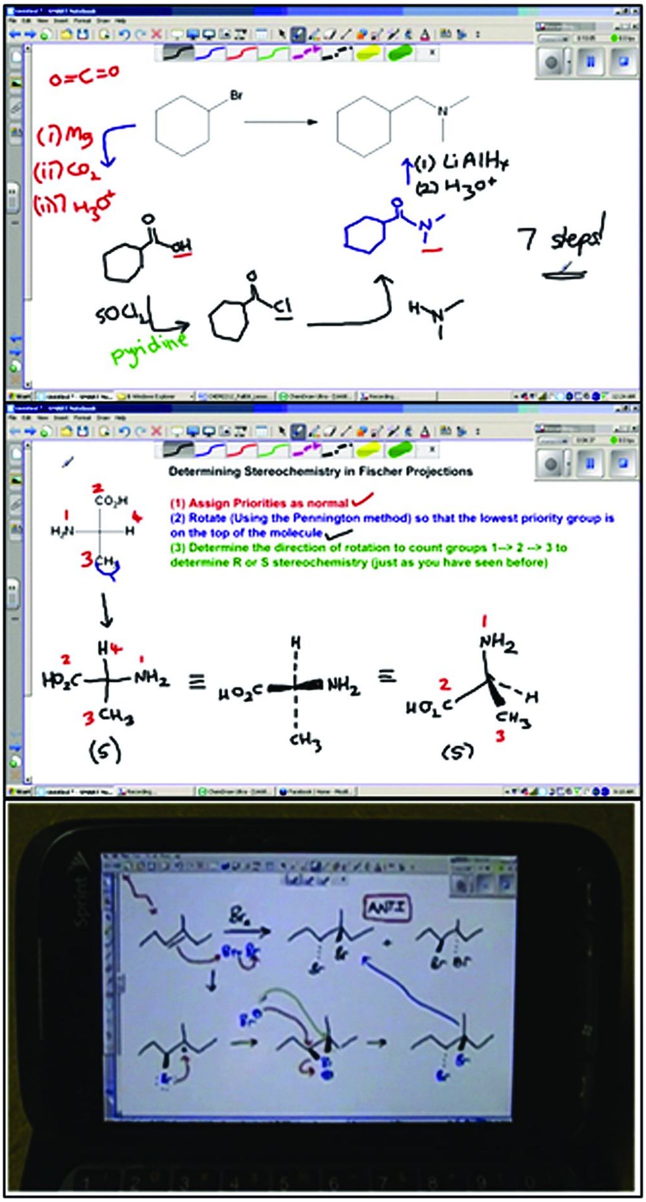
Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

Mini-Podcasts

Students use mini-lecture podcasts (Figure 8) created by GGC faculty using the Smartboard Airliner wireless tablet. These podcasts supplement the textbook study assignments and feature faculty audio "voice-over" of a white board "chalk-talk." Usually lasting between 10-15 minutes, these podcasts are unscripted and feature GGC faculty writing and talking about topics, as well as solving sample problems, of a type that students typically find the most challenging. One particularly effective aspect of these mini-lectures is that students control the pace - they may pause, rewind, or replay the mini-lecture until they understand the concept and are able to continue with their homework preparation. As a result, students are not as easily discouraged, and persevere with their pre-class and pre-lab preparation. Rather, they use the podcasts to help them overcome the barrier to self-teaching so that they are able to come to class with specific questions that increase student-teacher interactions and student critical thinking. After viewing the podcasts, students rarely come to class saying "I don't understand anything and couldn't even get started with the homework." Faculty have created an assortment of podcast mini-lectures for both semesters of organic chemistry, all available on the public GGC web page - and accessible by students 24 hours a day, seven days a week.

Mobile Apps

In this part of our project, we created a partnership between the organic chemistry and software development (SD) students and faculty. The chemistry students act as "clients" to the SD students. The SD students are tasked with designing, developing and delivering a working mobile application that helps chemistry students master a specific concept or topic. Throughout the semester the SD students get the real-world experience of interviewing and communicating with their clients, a large group of non-IT people. The continuous consultation with this group helps them design and develop a solution that best suits the client's needs. This process culminates in usability testing where the developers observe the clients use the finished product and gather feedback about the ease of use of the final product. Organic and SD students benefit immensely from this interdisciplinary partnership and both learn valuable skills and content that would otherwise be introduced and memorized from a traditional textbook and simple color diagram models. The partnership resulted in the design, development, and deployment of the "TsoiChem" mobile app (Figure 9) for organic chemistry functional groups. Additional apps are currently being developed.


O=C=O
Br
(i) Mg
(ii) CO2
(iii) H3O+
(1) LiAlH4
(2) H3O+
OH
7 steps!
SOCl2
pyridine
Cl
H–N
2 CO2H
1 H2N
H
4
3 CH3
H 4
2 HO2C
1 NH2
3 CH3
(S)
H
HO2C
NH2
CH3
1 NH2
2 HO2C
H
CH3 3
(S)
Br2
ANTI
Br

Determining Stereochemistry in Fischer Projections

(1) Assign Priorities as normal
(2) Rotate (Using the Pennington method) so that the lowest priority group is on the top of the molecule
(3) Determine the direction of rotation to count groups 1--> 2 --> 3 to determine R or S stereochemistry (just as you have seen before)

Figure 8. Screen shots of sample podcasts with synthesis on top, stereochemistry in the middle, and a mechanism as viewed on a handheld device on the bottom.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

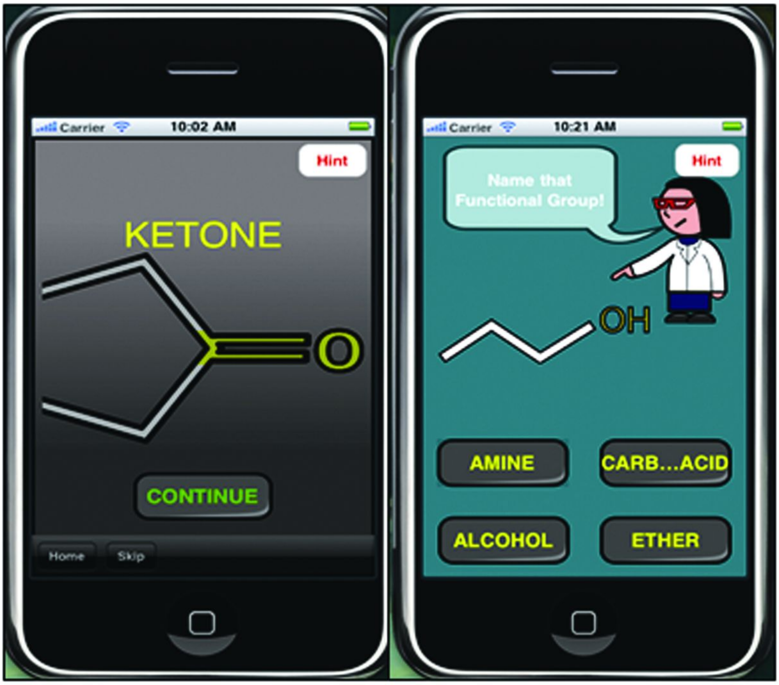

Carrier
10:02 AM
Hint
KETONE
O
CONTINUE
Home
Skip
Carrier
10:21 AM
Name that Functional Group!
Hint
OH
AMINE
CARB...ACID
ALCOHOL
ETHER

Figure 9. Sample screen shots of the Tsoi App.

Flashcards

Students new to organic chemistry typically memorize functional groups, structures, reactions and mechanisms, at least initially. Instructors intend that as students progress through the curriculum and study structure, properties, and mechanisms, the notion of memorization is replaced with one of understanding. However, the fact remains that most students must first memorize functional groups and reactions. To assuage the dread of organic and help students advance to the point of understanding, we developed a suite of organic chemistry flashcards (Figure 10) focused on nomenclature and reactions so that students could “drill” any time, any place (*36*).

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

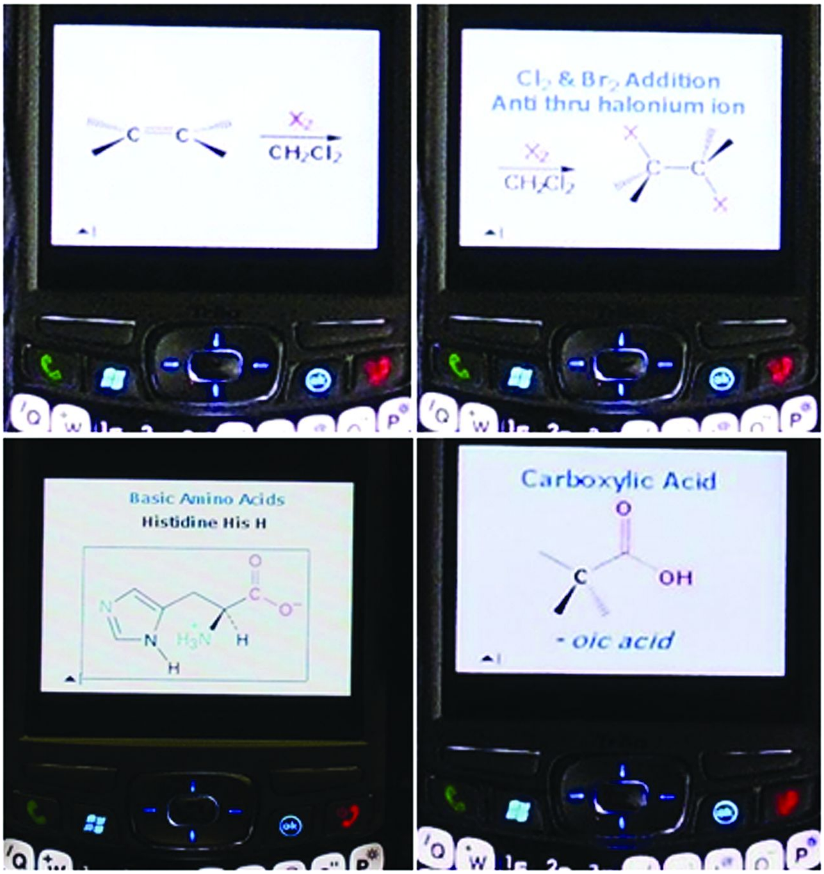


Figure 10. Sample flashcards as viewed on a handheld device with reaction cards on the top and nomenclature cards on the bottom.

Lab Techniques Videos

GGC organic chemistry faculty also created laboratory techniques videos (Figure 11) that demonstrate common techniques students perform during the laboratory portion of the course. These videos are unscripted and unrehearsed - simply faculty talking students through how to perform various laboratory techniques using the microscale glassware kits, or other equipment available in the laboratory. Perhaps the most promising aspect of the videos is that the instructor does not have to spend class or lab time demonstrating techniques, trying to gather a mass of students around a small piece of glassware where most are not able to see or hear the demonstration. Rather, students view the video before lab and can view it again during lab if needed, so that they have the full period to perform experiments. As with the lecture podcasts, students are able to pause, rewind and reply any section of these videos. This ensures that the student adequately absorbs the instructions and understands exactly how to perform the given procedure in a safe and effective way.

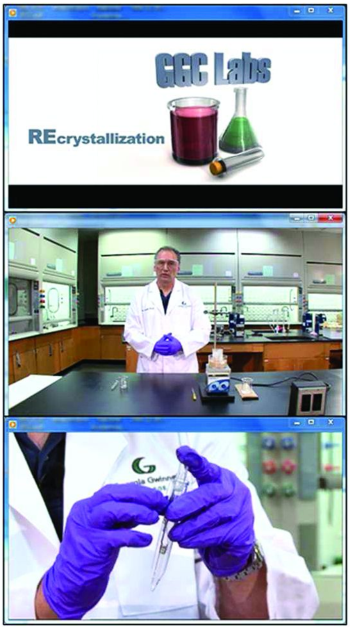


Figure 11. Screen shots of sample lab techniques video with the title screen on top, Dr. Sloop introducing the recrystallization technique in the middle, and close up of Craig tube apparatus on the bottom. (Photograph courtesy of David Eugene Gabrell)

Online Homework System

Most organic chemistry textbook publishers offer an assortment of supplemental materials, including chapter PowerPoint slides, solutions manual, online homework systems, etc. Organic faculty use online homework, but it is typically not graded and is not "mandatory" for students to complete. Online homework is one of many media types available for GGC organic chemistry students to complete homework assignments before coming to class and lab. The immediate feedback and online support of these exercises further enables the pre-class preparation required of students in our course, thus supporting the Thayer method of teaching and learning.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

GGC Organic Chemistry Wiki and Facebook Groups

To develop a more collaborative faculty and student learning community, we also use a wiki and organic chemistry Facebook group. Again, these media forums are not "mandatory," but as many students use them for non-organic chemistry applications, they serve as yet another venue for organic chemistry to become a part of their daily lives.

GGC Organic Chemistry in Action

Organic chemistry class and lab are active learning environments at GGC. They are environments where, through the use of the Thayer method, students do the work of learning while the faculty provide the guidance to enable learning (*37*). The environment is kinetic and includes both individual and collaborative work. Students attend class and lab in order to solidify their conceptual understanding and apply their knowledge through "hands-on" activities. A typical class period (Figure 12) includes initial discussion, Q & A, individual and collaborative board problems, recitation, and an end of class quiz. A typical lab period (Figure 13) includes individual (but collaborative) experimentation, record keeping, data analysis, and conclusions.

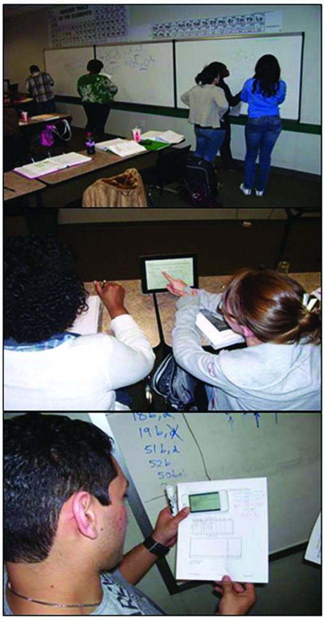


Figure 12. Typical class activities with students working at the boards on top, viewing course ebook in the middle, and podcast of spectroscopy information on the iPod Touch handheld device on the bottom. (Photograph courtesy of Richard Pennington)

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

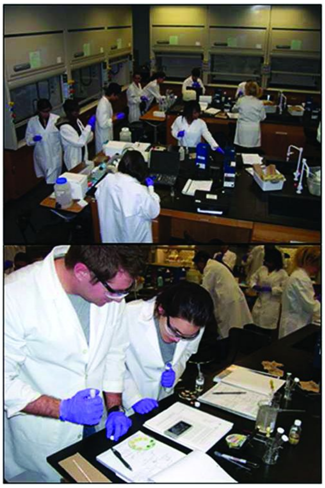


Figure 13. Typical lab activities with a section of students working on an experiment on the top and two students reviewing lab techniques videos via iPod Touch device at the bottom. (Photograph courtesy of David Pursell)

This active learning is ideal for utilizing mobile learning techniques. Because the ownership of the course lies in the hands of the students, a mobile device enables students to actively engage with the course whenever and wherever they see fit. It is the fact that at GGC our organic chemistry course is active and hands-on, making the choice of incorporating the mobile device a sound pedagogical decision.

What We Have Learned

We have been investigating the impact of using the 21st century Thayer method in organic chemistry for the past two years. Our results are not yet finalized and therefore unpublished. We have collected information and data through self-report surveys (chemistry and technology attitude, technology use, study habits and practice, etc.), student quiz and exam scores, tape-recorded individual student interviews, and systematic instructor observation of class and lab. We have just begun using the ACS Organic Chemistry Exam as the final exam in the Organic Chemistry II course, so our student ACS score sample size is small. Within a few semesters we anticipate sufficient ACS score data to at least provide some comparison with scores nationally. Once we are able to make such comparisons, our plan is to publish results via a journal article. For now, a summary of our tentative results follows.

- Over 90% of our students complete the two-semester organic class and lab with a C or better.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

- Students maintain a positive attitude toward organic chemistry - in part due to small section sizes, use of the Thayer method, and the mobile accessible suite of course content materials.
- Over 75% of students reported completing homework and practice problems prior to class.
- Most students prefer studying late at night rather than morning or afternoon.
- Over 70% of students completing the two-semester course integrate the use of the handheld resources into their study practice.
- Students accessing the course materials via mobile device generally perform better on quizzes and exams than students accessing materials via computers.
- Student attitude is mitigated by past technology experience, in that more familiarity with technology yields a larger increase in student attitude towards chemistry related tasks from the start to the end of the semester.
- When peers develop mobile application learning tools (TsoiChem app) and incorporate student feedback in its development, students favor its use.

These tentative results indicate that the GGC approach to organic chemistry has fundamentally changed the dynamic from one that views organic as a “weed out” course to one in which the faculty have a created an environment to enable student success through study discipline and perseverance.

Thayer Method for Large Section Sizes

The Thayer Method is designed for small section sizes with class conducted in rooms conducive to student group and board work. Many colleges have large organic section sizes and are conducted in auditoriums. One might then consider how to adapt a larger section size to the Thayer Method. Most educators are in agreement that small section sizes offer opportunities for engaging students beyond lecture, and when possible, are preferable to large section size because they increase opportunities for student success. However, large section sizes are less expensive to field for administrators, and as a result, are the norm at many colleges.

As a starting point, organic faculty and their dean should discuss the advantages and disadvantages of their current organic chemistry section size as compared to a small section size using the Thayer Method. If the student record of success in organic chemistry is weak at the college, perhaps the dean will apply additional resources (instructors and classrooms) to the organic program in order to enhance opportunities for student success by enabling pedagogical approaches such as the Thayer Method. A single instructor can effectively guide a maximum of about 20-25 students while they are working group or board problems. More students than this are beyond the “span of control” of a single instructor to effectively guide during activities. In addition to smaller section sizes, the Thayer Method is enabled by classrooms with multiple chalk or white

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

boards on which students can work and present results to classmates in an efficient manner. Organic chemistry classrooms with white board space for all students are ideal. As most students have cameras on their phones, camera phone photos of white board work provides a relatively low tech, low cost, but effective method for students to present work to classmates and maintain copies of the work for notes. Alternatively, digital white boards or individual tablets provide a high tech, high cost alternative if funds are available to outfit classrooms and students with these devices.

Single instructors could adapt section sizes of up to about 50 students, twice the ideal number of students, to the Thayer Method by dividing the section into two teams of ideal Thayer Method size. Smaller teams create a more intimate atmosphere in which the instructor guides the activities while students maintain responsibility for their learning. When the more intimate environment is lost, some students will avoid this responsibility and are thus less likely to participate and more likely to be unsuccessful. The instructor's imagination could guide team creation: male-female; chemistry majors-non majors; student selected; random assignment; etc. Team composition could be shuffled during the semester. The instructor could then alternate teams working at the white boards and at the classroom desks for specific problems or specific class periods. In this case, students are receiving roughly half the attention/guidance from the instructor as they would in an ideal Thayer Method size class. The important point is that the instructor and students, through daily activities that includes critical feedback, gauge their progress in meeting lesson objectives. With a single instructor and section sizes more than about 50 students, the quantity and quality of instructor-student interactions is such that the Thayer Method loses its effectiveness.

As an alternative to a single instructor, larger sections could also be managed by adding upper level undergraduate or graduate student teaching assistants (TA). In using TAs with the Thayer Method, it is important that the TAs are trained and practiced in how to mentor/guide student groups in problem solving. This skill in guiding students is perhaps as important as the TA's knowledge of the chemistry. Workshops in which TAs learn about the Thayer Method and then practice guiding each other in problem solving sessions is helpful in providing TAs the skill and confidence they require to effectively and efficiently guide novice students. Many schools use TAs to lead recitation sections as supplemental to large section lecture by the instructor. Often these recitation sessions are not "mandatory" and the TA merely answers student questions or solves particular problems students raise during the recitation meeting. This common recitation section model is a passive activity and does not maximize student engagement as does the Thayer Method. Therefore, schools that use an instructor lecture model supplemented with a weekly TA recitation section might better be served by adapting a Thayer Method approach for the recitation section. In this case, the TA must be trained and practiced in the method, student attendance should be mandatory (graded), the classroom requires sufficient student white board space (or other accommodation), and the session must engage and challenge students in activities and hold them responsible for their progress.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

Professor Robert J. Beichner of North Carolina State University has developed SCALE-UP (Student-Centered Active Learning Environment with Upside-down Pedagogies) methods for large sections (*38*, *39*). SCALE-UP is similar in many ways to the Thayer Method. SCALE-UP's fundamental emphasis is on instructor-student and student-student interaction and individual accountability. It is an active learning environment, initially developed for undergraduate physics courses but has been adapted across STEM as well as social science courses such as economics. Perhaps most important, SCALE-UP has been successful at enhancing student learning. Those desiring more information on SCALE-UP should visit Dr. Beichner's web site (*40*).

Conclusion

The Thayer Method, coupled with a course content suite of handheld accessible and viewable materials, enables 21st century students to learn and practice organic chemistry "when, where, and how" they live – 24 hours a day, seven days a week. Organic chemistry at GGC is a dynamic, positive learning community of students and faculty that engages well beyond the confines of the traditional classroom. Contrary to undergraduate organic chemistry students' experience with "the infamous, dreaded 'orgo', a marathon of memorization" in which 25-50% of students do not succeed, GGC students maintain a positive attitude about chemistry and have over 90% success rate in completing the two semester course sequence. As a result, our approach enables students to pursue their chosen profession without reducing organic chemistry to a "weed out" course and to small measure is staunching the flow of students out of the STEM pipeline.

Acknowledgments

The authors thank the Georgia Gwinnett College Vice President for Academic and Student Affairs Seed Grant Program and the Vice President for Educational Technology for funding and technical support of the project.

References

1. Silverman, R. E.; Light, J. Generation Jobless: Students Pick Easier Majors Despite Less Pay. *The Wall Street Journal*, November 9, 2011, http://online.wsj.com/article/SB10001424052970203733504577026212798573518.html (accessed 04/16/2012).
2. Thibodeau, P. Obama: We don't have enough engineers. A look at the numbers behind the president's call for 10,000 new engineers in the U.S. *ComputerWorld*, June 14, 2011, http://www.computerworld.com/s/article/9217624/Obama_We_don_t_have_enough_engineers_ (accessed 04/16/2012).
3. Drew, C. Why Science majors Change Their Minds (It's Just So Darn Hard). *The New York Times*, November 4, 2011.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

4. Lederman, D. Teaching is Key to Producing More Science Graduates, U.S. Says. *Inside Higher Education*, February 8, 2012.
5. Gawelek, M. A.; Spataro, M.; Komarny, P. Mobile Perspectives: On iPads, Why Mobile? *EDUCAUSE Review* **2011**, *46* (March/April).
6. Parry, D. Mobile Perspectives: On Teaching Mobile Literacy. *EDUCAUSE Review* **2011**, *46* (March/April).
7. Ophir, E.; Nass, C.; Wagner, A. D. Cognitive control in media multitaskers. *Proc. Natl. Acad. Sci. U.S.A.* **2009**, *106*, 15583–15587.
8. Young, J. R. A Tech-Happy Professor Reboots After Hearing His Teaching Advice Isn't Working. *The Chronicle of Higher Education*, February 12, 2012, http://chronicle.com/article/A-Tech-Happy-Professor-Reboots/130741/ (accessed 03/03/2012).
9. GGC Web page, http://www.ggc.usg.edu/about-ggc (accessed 03/03/12).
10. Kaufman, D. J. President of Georgia Gwinnett College, New Faculty Orientation, January 5, 2010.
11. Zurer, P. S. *Chem. Eng. News* **2001**, *79* (16), 42–43.
12. Pienta, N. J. Celebrating the Chemical Education Connections to Health and Medicine. *J. Chem. Educ.* **2011**, *88*, 1343 (editorial).
13. Katz, M. *J. Chem. Educ.* **1996**, *73*, 440–445.
14. Smith, M. Johns Hopkins Aims to Reform Early Science Classes. *Inside Higher Ed*, January 23, 2012.
15. Steiner, R.; Sullivan, J. *J. Chem. Educ.* **1984**, *61*, 1072–1074.
16. Bunce, D. M. *J. Chem. Educ.* **2009**, *86*, 674–680.
17. Oliver-Hoyo, M. T.; Allen, D. *J. Chem. Educ.* **2005**, *82*, 944.
18. Oliver-Hoyo, M. T.; Allen, D.; Hunt, W. F.; Hutson, J.; Pitts, A. *J. Chem. Educ.* **2004**, *81*, 441.
19. Hinde, R. J.; Kovac, J. D. *J. Chem. Educ.* **2001**, *78*, 93.
20. Katz, M. *J. Chem. Educ.* **1996**, *73*, 440.
21. Landolt, R. G. *J. Chem. Educ.* **2006**, *83*, 334.
22. Frydrychowski, V. A. *J. Chem. Educ.* **1995**, *72*, 429.
23. Hass, M. A. *J. Chem. Educ.* **2000**, *77*, 1035.
24. Dougherty, R. C. *J. Chem. Educ.* **1997**, *74*, 722.
25. Browne, L. M.; Blackburn, E. V. *J. Chem. Educ.* **1999**, *76*, 1104.
26. Neeland, E. G. *J. Chem. Educ.* **1999**, *76*, 230.
27. Almeida, C. A.; Liotta, L. J. *J. Chem. Educ.* **2005**, *82*, 1974.
28. Kurtz, M. J.; Holden, B. E. *J. Chem. Educ.* **2001**, *78*, 1122.
29. Casanova, R. S.; Civelli, J. L.; Kimbrough, D. R.; Heath, B. P.; Reeves, J. H. *J. Chem. Educ.* **2006**, *83*, 501.
30. Kutz, M. J.; Holden, B. E. *J. Chem. Educ.* **2001**, *78*, 1122.
31. Fountain, K. R. *J. Chem. Educ.* **1997**, *74*, 354.
32. Toth, L. S.; Montagna, L. G. *College Student Journal* **2002**, *36*, 253.
33. *Academic and Military Programs of the Five Service Academies*; Comptroller General of the United States, Report to Congress; October 31, 1975; pp 48−52.
34. Palladino, G. F. *J. Chem. Educ.* **1979**, *56*, 323.
35. Ertwine, D. R.; Palladino, G. F. *J. Coll. Sci. Teach.* **1987**, *16*, 524.
36. Pursell, D. P. *J. Chem. Educ.* **2009**, *86*, 1219–1222.

37. Paredes, J.; Pennington, R. L.; Pursell, D.; Sloop, J.; Tsoi, M. *Ga. J. Sci.* **2010**, *68*, 186–195.
38. Beichner, R. *The SCALE-UP Project: A Student-Centered, Active Learning Environment for Undergraduate Programs*; White paper for the National Academy of Sciences, September, 2008.
39. Gaffney, J. D. H.; Richards, E.; Kustusch, M. B.; Ding, L.; Beichner, R. *J. Coll. Sci. Teach.* **2008**, *37*, 48–53.
40. SCALE-UP web page, http://scaleup.ncsu.edu/ (accessed 04/03/2012).

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch012

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch013

Chapter 13

Using Short Videos To Supplement Lectures on Reaction Mechanisms, Organic Spectroscopy, and Polymer Chemistry

Arno Kraft,* Emma S. Rankin, and Valeria Arrighi

**Institute of Chemical Sciences, School of Engineering & Physical Sciences,
Heriot-Watt University, Riccarton, Edinburgh, Scotland EH14 4AS,
United Kingdom
*A.Kraft@hw.ac.uk**

We have developed a series of short videos that are 5 – 12 minutes long and introduce students to topics such as curved-arrow reaction mechanisms, spectroscopic methods, the polymerization of styrene, and various polymer characterization techniques. The videos are designed to supplement lecture courses or lab classes, as well as serve students as additional exam preparation tool. The various videos help students who are struggling with lectures, who enter the undergraduate program late, or who have simply forgotten elementary skills. The videos introduce students to the topic at a fast pace, emphasize key features, use simple "visual effects" and aim to entertain, but avoid the normal Powerpoint presentation-style lecture. Advantages and disadvantages of this teaching approach, and the impact on student understanding and comprehension will be discussed.

Introduction

Computers have now become an integral part of everyday life and are used extensively in many different fields. One of these is education where computers provide new opportunities to enhance and develop learning experiences (*1*). Teaching and learning has moved from "chalk and talk" to incorporating multimedia and technology into lectures and classes. With the arrival of the internet, vast quantities of information are now readily available for anyone to

In Advances in Teaching Organic Chemistry; Duffy-Matzner, J., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2012.

view. However, it is still essential to ensure that the technology used in class meets the needs of the students (*2*).

The generation of students now attending university are different from their predecessors, in that they have grown up with computers, video games and the internet (*3*). These "digital natives" have never experienced a world without Information and Communication Technologies (ICT). Current students have not only good ICT technical skills but also ways of learning and thinking that are radically different to previous generations of students (*2*, *4*). Therefore, new methods of teaching have to be considered, in order to bridge the divide between current teaching methods, of chemistry in particular, and how new students learn (*5*).

Distance learning courses have been available for some time, with material originally being delivered by post. Now, many universities are taking advantage of the internet, and there has been a recent move towards online learning, where lecture notes, tutorials, etc., are all available through the internet or university-owned intranet. Many universities and colleges offer online learning activities in conjunction with more traditional lectures and tutorials, for distance learning students, as well as to support students present on campus. These are available through a Virtual Learning Environment (VLE) which allows lecturers to post announcements, lectures notes, tutorials and other learning material for students to access and view.

Many websites that focus on chemistry topics have been developed for academic purposes. Lecture notes, homework projects, online books and even complete courses in chemistry can now be accessed on the internet (*6*). In addition to lecture notes being posted on these online learning environments, more and more lecturers have started to post video resources online as well. These could be video recordings of lectures, demonstration videos, or supplementary purpose-made tutorial videos. It is becoming easier to make and post videos online, as technology becomes cheaper and easier to use. Television and video have been used for many years as an additional means of teaching. Many students like to learn using videos, as they feel they invest less mental effort into watching a video than from reading print, so making learning "easier" (*7*). Videos can offer many multimedia possibilities to create highly motivating and detailed instructional sequences (*8*).

Videos and podcasts are often used synonymously. A podcast is a downloadable audio or video file, which is usually released episodically. Podcasts have been used primarily for entertainment, but many universities are now extending their use for educational purposes. It is even possible to download university-level podcasts from websites such as YouTube or Apple's iTunes University, or from university-owned sites, such as MIT's Open Courseware initiative (*9*), or the Berkeley Webcast service (*8*). Part of the reason behind the rise in the availability of podcasts is the popularity of mobile media devices, such as music players, smartphones and tablets, which are becoming more and more popular and allow students to rapidly access information online. Many students now own a form of media player or other mobile device, and these are highly valued by students. This technology can play videos, and universities and other educators are seeking to capitalize on the popularity of these devices, through

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch013

the development of videos that can be downloaded onto mobile media devices as well as computers, and so can be viewed anywhere by the student (*10*).

Advantages of Online Video Learning

The use of videos in online learning has many advantages over more traditional forms of education. Pedagogical advantages could be described as the "4 p's"; place, pace, peace and process (*11*). The videos do not have to be watched in a set place and time. As long as there is access to the internet, students can download and watch them anywhere. This means that they can be viewed at a time and location that best suits the student. The students can learn at their own pace, revisiting the parts of the course which they may have found more difficult and taking the time to understand these, without the need to keep up with the rest of the class. Unlike a lecture, videos can be played again and again, so are useful for reviewing (revision) purposes. Being able to download videos instantly students gain immediate access to the material they need. Supplementary tutorials could also be used for the benefit of advanced or well motivated students, who wish to research more on a particular area. Videos also provide additional assistance to students with reading, hearing or other disabilities (*1*). Videos may be used to instruct students on practical techniques, such as how to carry out an experiment, or how to operate a laboratory instrument.

Learners process information through two separate channels; visual and verbal (*12*). Learning is therefore best obtained by presenting these two stimuli in a synchronized fashion, instead of separately. The use of videos in education allows teachers to incorporate more visual learning into their lectures. Multimedia, such as videos, can make learning easier because it appeals more readily to diverse learning preferences (*13*). However, there is the danger that learners could be "overloaded" with information, as there is a maximum capacity for the amount of information that can be processed by an individual at any one time. Podcasting could limit this, as learners can view the video again, control the speed, and repeat parts they are unsure of. Podcast videos and synchronized files then have the advantage over other types of learning resources. Students can decide the time in which they learn, choosing moments of peace and quiet most suitable for learning.

Videos add diversity to learning. Many students are more receptive to learning materials in the form of a podcast than a traditional lecture or textbook, believing that they are more effective reviewing tools than textbooks and more useful than their own notes in helping them to learn (*14*). The use of audio and video may benefit students with different learning styles, or students who require extra help with their learning. Learning through listening benefits those students whose learning style is mainly auditory, while visual learners may find seeing videos more useful (*10*). As many of the videos allow the students to fast-forward and concentrate on the parts of the video that they find challenging, students can therefore select how they learn, choosing the learning process that is most suitable to them (*15*). Much of the study material presented and used at university is in read-only form (books, handouts, lecture notes, etc.). While many people will benefit from this, videos may be of assistance to those who prefer other styles of

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch013

learning. Videos can directly portray complex processes and may go beyond the language or cultural dependencies of text (*8*). Finally, for students who missed lectures, videos provide an opportunity to catch up and may be of more use than simply copying notes (*16*).

Disadvantages of Online Video Learning

Online learning is not without its disadvantages and this can have a huge impact on its use. Again, these can be described using the "4 p's"; pub, plod, procrastinate, and play (*11*). While online learning allows students to download and watch videos anywhere, it also means they may choose inappropriate places to do so, such as in a pub (tavern). They may also "plod" along at an unsuitable pace and do not complete the work in time. Having the freedom to choose when they learn allows students to procrastinate or to waste time by playing e.g. computer games, putting off using the learning material until the last minute. If students can choose the processes by which they learn, they may opt for one that is unsuitable, and so not concentrate on their work and ultimately not complete it. Online learning material of any type requires good time management skills and self-discipline and, if students lack these, then they may fall behind.

Often, online learning is not fully integrated into the curriculum. This can limit its effectiveness and many students and tutors may disregard it completely. Podcasts may be unpopular with some students. While many students currently at university have grown up around technology, others may still be put off by "online learning". This applies especially to older students. The material therefore needs to be easily accessible and set out in a user-friendly way. As the videos and other material require to be downloaded before viewing, a potential problem arises if students are unable to connect to the internet or internet connections are slow. Large video file sizes will take longer to download, which again will be discouraging. A possible solution to this problem is for videos to be made available in a lower resolution. This, however, may produce low-quality videos. A further problem might be the inability of a student's computer to handle the files, or the computer crashing or the monitor freezing, again causing frustration. Although ICT is a powerful instructional device, there is still some debate as to how multimedia technology can promote students' understanding (*17*).

Videos that are too long will also put students off (*15*). Despite growing up with television, computer games and other visual stimuli, it is harder to concentrate on this than on printed material. Also, many students are already overloaded on time, and may not have time for using online learning and podcasts.

Although beneficial to promote both visual and verbal processing of information, if students are presented with vast amounts of information, without adequate time for processing, then cognitive overload may occur and the learners will fail to understand the content, which then may become confusing (*14*). Also, if students are already regularly using other forms of learning, then the addition of yet another may cause overload. If learners do not realize the self-pacing benefits of podcasting, then this resource will not be used. Not all multimedia technologies are appropriate as effective strategies for improving student knowledge acquisition from web-based instructions.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch013

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch013

The preparation of the videos themselves may equally cause problems. Lectures and tutorials can be recorded relatively easily, so these may form the basis of online lectures. However, any supplementary teaching material takes much longer to plan and prepare. It is easier and quicker for tutors to give a traditional lecture than it is to make a video. Many students feel that online lectures cannot replace real lectures and feel that they benefit from the interaction and being able to ask questions, neither of which is possible with online lectures.

How Online Learning Can Be Used To Help Students Understand Chemistry

Learning and understanding university level chemistry is difficult for many students due to the complex and theoretical nature of many chemical concepts. Recently, online learning has been integrated into many chemistry courses, and revealed many educational benefits. Just as laboratory work can help students understand reaction processes, the incorporation of online and computer learning into courses can reinforce the understanding of many of the basic chemical theories, concepts, and molecular structures. The integration of texts and multimedia environments can help students to develop meaningful concepts, as well as the unifying principles which can enhance the student's understanding (*18*). For example, molecular modelling programs can help develop a student's visualization skills and can provide illustrative models for difficult concepts (*19*). By being able to see molecular structures in 3 dimensions, students may better understand theoretical concepts. Many websites now even run "virtual laboratories", such as TheChemCollective.org (*20*). In the chemistry program at Heriot-Watt, computational chemistry experiments are part of the inorganic, organic and physical chemistry laboratories. Online learning in the form of a "pre-lab" is also used to help students to maximize their time in the laboratories.

For students who are accustomed to using the internet and associated technologies, this is possibly the first place that they will look when searching for information, owing to the vast amount of information that is available online. It makes sense, therefore, for universities to provide learning material for their students in an environment that they are familiar with. Students often have many demands on their time and so many choose to study at lunch, or while travelling (*21*). The use of portable technology, such as podcasts, makes it easier for students to study when and where they want (*14*).

Aims

The purpose of this chapter is to illustrate how short video tutorials can be used to supplement lectures across various years of the undergraduate program. The discussion will concentrate on the development of a teaching video covering the basics of curved arrows in writing organic mechanisms. We have also introduced supplementary videos in other areas of organic chemistry (*viz.* NMR, IR and UV-VIS spectroscopy, and mass spectrometry), and even to cover aspects of polymer synthesis and characterization. Advantages and disadvantages of this approach, and the impact on student understanding and comprehension will be discussed.

Results and Discussion

Problems Students Encounter with Curved-Arrow Mechanisms

Curved arrows (sometimes also called "curly arrows") illustrate the movement of electrons during an organic chemical reaction. The movement of electrons explains the formation and fission of bonds, and this is the basis of most organic chemistry reaction mechanisms. Electrons move from high electron density areas to low electron density areas. Curved-arrow mechanisms are a way of keeping track of the movement of electrons during a reaction, when bonds are broken and formed.

Curved-arrow mechanisms are fundamental to understanding organic reactions, but many students have trouble understanding and using these. There are four main areas where students have difficulties: inability to recall, inability to apply or understand, poorly understood content, and non-content-specific barriers (*22*). With the first barrier, inability to recall, some students are relying on memorized facts to solve problems, rather than trying to work out the answer. This leads to students being unable to remember certain parts and so they make mistakes. Inability to apply or understand sees the students misapply information that they have understood and memorized. They get mixed up between reactions or reagents, or give a right mechanism, but one that does not relate to the question. With poorly understood content, students often do not understand curved-arrow mechanisms to begin with and so struggle to answer questions. The final category, non-specific barriers, deals with barriers that involve the spatial reasoning abilities of the students (*22*). Students do not connect their learning to what is being asked of them in the question. Learner's barriers are often limited to certain parts of the course, but can cause problems for a student in answering a wider range of questions. New information has to be linked to previous learning for it to be retained correctly. If this is linked properly, then meaningful learning can occur. If new knowledge is linked incorrectly to previous knowledge, then misconceptions arise (*23*). Many of the problems students have with curved-arrow mechanisms, particularly in later years of the chemistry program, are due to poorly understood learning and ineffectual linking to previous learning, creating misunderstandings.

We therefore felt strongly that a teaching video covering the basics of curved-arrow mechanisms would be highly beneficial in supporting chemistry students in their first year. The video supplements the organic chemistry course material on a VLE where students can access it easily, and either watch it online, or download it onto a computer or portable device.

The topic of the video was chosen for several reasons. Primarily, many first-year students who are encountering curved arrows for the first time need additional help to understand the fundamental concepts, particularly during preparation for exams. Secondly, the video may be used by returning students who would like to refresh their knowledge of curved arrows. Thirdly, the video serves as support material for direct entry students into 2nd and 3rd year, who have missed this taught part of the course. The video is designed to help them catch up.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch013

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch013

What Is Included in the Video

What to put into the video and what to leave out is one of the most difficult decisions which have to be faced up-front. The video was intended to provide a summary of key features on how to draw mechanisms. It does not go over the whole lecture course, and only basic mechanisms were covered. The video was designed to be brief, and no more than 15 minutes in length. To help us decide what should be included in the video, we reviewed both first-year lecture notes and past exam papers, in conjunction with a standard monograph on how to write reasonable organic reaction mechanisms (*24*). We finally selected the following material in the video:

- A "basics" section
- Nucleophilic substitution reactions (S_N1 and S_N2)
- Elimination reactions (E1 and E2)
- A summary comparison of substitution and elimination reactions
- Addition reactions to the carbon–carbon double bond of an alkene, and to the carbonyl bond
- Electrophilic aromatic substitutions

The basics section covered the fundamentals of curved arrows. We deemed it important to reiterate the difference between single and double headed arrows, and where the arrow will point to (*24*). Students must understand the basic concept before going onto more complicated reactions, and so this section was crucial and it also made a good introduction to the video.

Substitution reactions feature considerably in the lecture course, as do elimination reactions. They are the most basic and simplest reactions covered in the first-year lectures. They are not covered in great detail again later on in the undergraduate syllabus, so students in higher years may wish to go back and review them. For this reason a short summary comparison of substitution and elimination reactions was included. This covered the reaction conditions and also the similarities in mechanism between S_N2 and E2, and S_N1 and E1.

The video further mentioned both electrophilic additions to an alkene and nucleophilic additions to a carbonyl group. Carbonyl chemistry is the backbone of organic chemistry. However, only simple additions (*e.g.* Grignard reaction) and condensation reactions (*e.g.* the formation of an oxime between a ketone and hydroxylamine) were covered in the video. Electrophilic aromatic reactions also feature in first-year lectures and again are built on in later years, when the chemistry of organometallic compounds and the synthesis of heterocycles is discussed. We covered one example (a Friedel-Crafts alkylation) in more detail, and mentioned three other reactions (Friedel-Crafts acylation, halogenation, nitration). We did not include any more reactions, or discuss the directing effect of existing groups, as we felt that this may be too in depth for a video like this, and again may increase the length too much.

For all the reactions, only one representative example of each mechanism was presented, as more might make the video too long. Students may lose concentration and a longer video may distract from the core material. We selected examples with simple reactants or nucleophiles. The examples that were used were changed as much as possible, to try to keep the video interesting (*i.e.* by changing the nucleophile or the leaving group).

Some content of the first-year course was left out by necessity, to keep the video short and well below the 15 minute time limit. Hence, we decided not to cover reactions such as the formation of phenylhydrazones, reactions of carboxylic acids and derivatives, enols, enolates, and radical chlorinations. These reactions are more complicated, and best covered once a student has understood the basics. Their omission also prevented overload of information for students, so making the video more interesting.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch013

How the Video Was Made

Once the general outline of the video had been decided, the next step dealt with the writing of a script, *i.e.* of what was to be said in the video. This took several weeks and many drafts to get the script "word perfect". A storyboard was created at the same time as the script, which again took a while to develop. The main purpose of the storyboard was to collect ideas of what would be shown visually at each point.

When the script was more or less finalized, it was recorded using a standard dictaphone. After editing, the audio stream served as a template where to place the various video sequences, photo stills, and animations.

The hand-drawing of mechanisms on a whiteboard was filmed with a camcorder. Some still shots were taken with a digital camera. The rest of the video consisted of PowerPoint slides and animations which were recorded using screen capture software.

Occasionally, we encountered difficulties matching the script to the storyboard, or periods of inactivity on screen when viewers might easily lose interest, which required adjustements to the script or the inclusion of extra scenes in some parts, or cuts in other parts. Apart from the need to reshoot certain sequences, a major effort during "post-production" included the polishing of the video, checking for consistency between the visuals and the spoken word, including text labels in form of call-outs, and improving the sound quality (*e.g.* removing breathing sounds or background noise). Although overall quite tedious and time-consuming, it was felt that a good quality video would be better perceived and also more extensively used by students.

Keeping the length of the video below 15 minutes was an ongoing issue during development. Any longer, and students may lose interest while watching, or not bother to watch it at all. Both the script and storyboard were edited heavily to keep the video succinct. The video was made available to undergraduate students across years 1 – 3 via the VLE where students can either stream it online or download it for viewing (*25*).

Why the Video Was Made This Way

We considered two alternative ways in which the video could have been created. Our initial intention was to show every mechanism being drawn "live" by hand on a whiteboard (Figure 1). Seeing someone drawing out the mechanism by hand is beneficial to the learning and understanding process. However, it was decided not to solely create this video this way for several reasons. Recording the scenes with a camera required many takes. All shots had to be heavily edited afterwards, and this turned out to be not very time-effective. Repetitive viewing of someone drawing on a whiteboard may also be monotonous; therefore to encourage students to watch the entire video a more varied approach was taken.

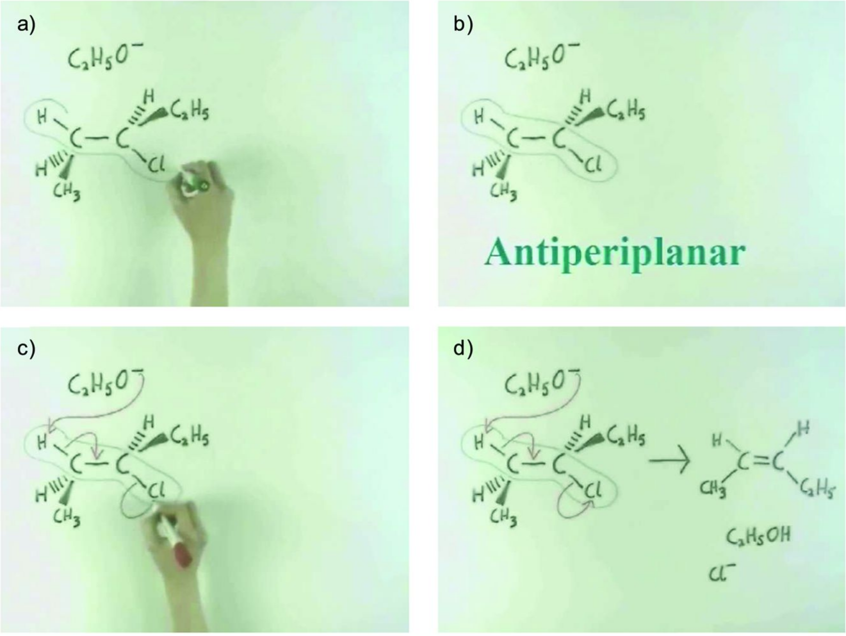


Figure 1. Hand-drawn E2 elimination mechanism: a) key atoms involved were highlighted; b) the label "Antiperiplanar" was included using video editing software; c) each curved-arrow was drawn in concert with the spoken word; d) the finished mechanism.

Alternatively, the scenes could have been created entirely in PowerPoint, using computer-drawn structures and mechanisms, and recorded with the help of screen capture software. This method is quicker to produce and easier to edit. However, we decided against such an approach for the whole video. The majority of lectures nowadays tend to be based on PowerPoint and there is a danger of students becoming discontented with yet another PowerPoint presentation. Eventually we opted for a mix of the two as the best compromise in terms of time-effectiveness and keeping students interested. The final video contained a combination of live video recording, PowerPoint slides, animations and still photographs.

Color was employed extensively, as use of color can be visually stimulating. The attacking nucleophiles were colored in blue, leaving groups in green, and curved arrows in red and this was used consistently throughout the video. By

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch013

drawing the curved arrows in red, they could not only be distinguished from reaction arrows, but would also stand out visually, especially on the whiteboard where color is harder to see.

The video included a number of simple animations, an example of which is shown in Figure 2. When the basics of drawing curved arrows were discussed, an archer shoots a curved arrow from the source of electrons (the lone pair of a carbonyl group) to the electrophile (a proton in this case).

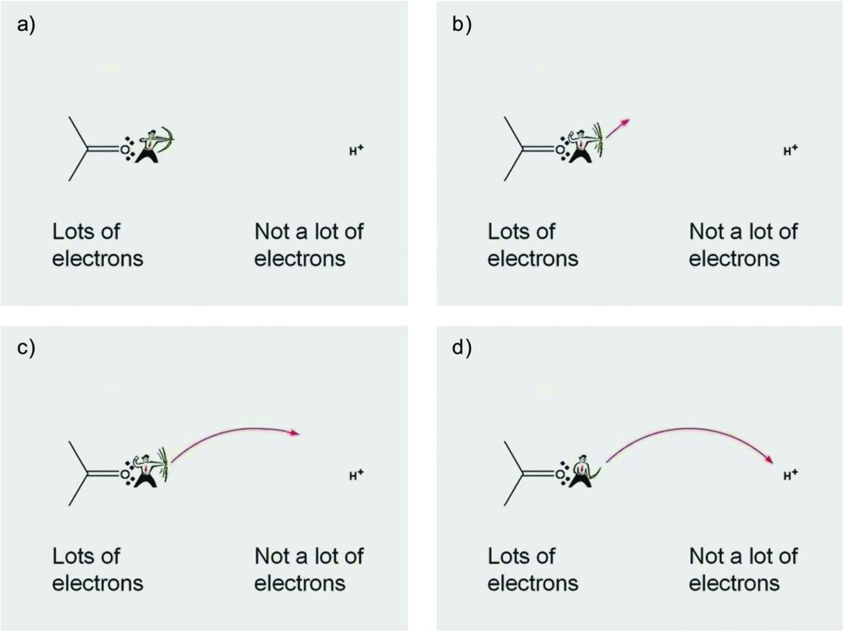

a)
H^+
Lots of electrons
Not a lot of electrons
b)
H^+
Lots of electrons
Not a lot of electrons
c)
H^+
Lots of electrons
Not a lot of electrons
d)
H^+
Lots of electrons
Not a lot of electrons

Figure 2. Picture sequence of an animation in the video where an archer shoots a curved arrow.

An unconventional approach, such as an animation like this, is more likely to engage and stimulate the viewer’s interest, encouraging him or her to continue watching the video. Curved arrows could be easily animated in PowerPoint, which not only made the video more visually attractive, but also allowed students to see where the arrow starts and where it finishes. The problems students have with curved-arrow mechanisms are often linked to students being unable to “visualize” the problem. By judicious use of animations, mixed with cartoons and narration of how the reaction proceeds, students will be encouraged to see more clearly how to draw a curly-arrow reaction mechanism. A combination of animation with narration and pictures leads to better understanding than text alone, as connecting verbal and visual representations can help students understand difficult concepts.

We were also conscious that students might be watching the video on portable devices with a small screen size. We therefore checked that all pictures and text were clearly visible even on a small screen. For this reason, lengthy multi-step mechanisms were not shown completely on one screen, but instead each stage

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch013

of the reaction appeared on a different slide, and the mechanism was "flicked" through. This approach also made it possible to illustrate what resonance means; for example, the various resonance forms of a Wheland intermediate in an electrophilic aromatic substitution were cycled through on screen thus giving the illusion of the positive charge being delocalized around the ring (Figure 3). The full mechanism could thus still be shown, but remained clearly visible on a small screen. If lots of information and pictures are present on screen, students may not be able to process it all, so this also prevented visual overload of the students, as they were only viewing one step at a time. Information may be missed if the screen is not paused for long enough. By limiting what is seen on screen, the video remains clear and does not overload the viewer. Therefore anyone watching has the opportunity to fully process and understand what they see.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch013

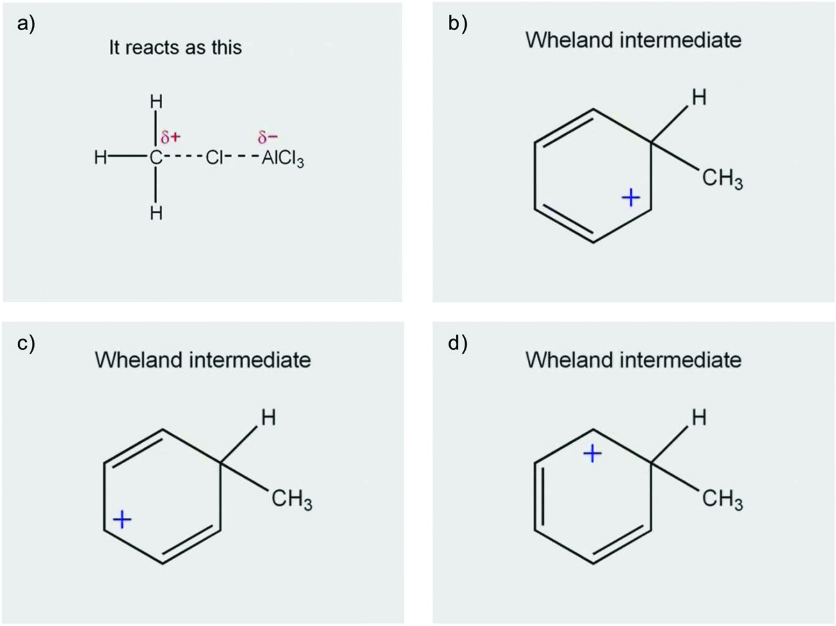


Figure 3. Picture sequence illustrating a Friedel-Crafts alkylation: a) structure of the electrophile; b-d) while the Wheland intermediate is discussed, resonance is illustrated visually by cycling through the 3 images every 2 seconds thus creating an illusion of the positive charge being delocalized around the ring.

What the Students Thought

The curved-arrow mechanism video was made available to 61 students in 1st year as part of the support material for the organic chemistry laboratory throughout February and March 2012. Over the 7 weeks of the laboratory, students accessed the video 742 times. Each student viewed the video at least once and on average 12 times.

A survey was carried out amongst first-year chemistry undergraduates who had watched the video (12 students). The students were asked various questions about the video in particular and teaching videos in general with a choice of three answers provided.

Most students (75%) were satisfied with the quality of the images and pictures in the video and no-one stated that they were not clear. Some students commented that the diagrams were clear and easy to understand and that they liked the animated arrows, as this had helped them understand the concepts. A further point was noted that simplifying the topics by breaking them down step by step made them much easier to follow.

The majority of the students (92%) noted that the video was easy to follow. Several of the students commented that the sound quality could be improved. It sometimes "crackled" and the audio was louder in some parts than in others. Sound quality was subsequently improved by digitally removing background noise or breathing sounds from the audio stream. Professional recording equipment might have avoided this problem, but was not a practical or affordable option.

Most of the students (75%) thought that the pace of the video was about right. However, 17% thought that it was fast, while 8% thought that it was slow. This was quite an interesting question to ask, as what is too fast for one student could be too slow for another, and so finding the right pace is challenging. It can be concluded however that the video was at the right pace for most of the students.

While the video was designed to be interesting enough to hold their attention, students had mixed views on this, with 75% considering the video as interesting, 17% as only partly interesting, and 8% as not interesting. As the main purpose of the video was to help students with their learning, it is quite encouraging that the video was considered interesting by the majority of the students. Part of the interest might have come from a video being an alternative to the normal way of learning from notes and textbooks, as this is an innovative way of presenting material, and one not seen by students before.

It is likely that more video tutorials will be made to help students and so it was essential to determine how helpful they thought this form of learning was to them. These numbers are encouraging as 67% of the students asked thought that the video tutorial was very helpful and 33% thought that it was helpful. None of the students asked thought that it was unhelpful. Several of the students commented that it was easier than reading a textbook and was useful for clarifying points they were unsure of. It was also commented that being able to fast forward and rewind the video to points of interest and difficulty helped them in their understanding. It can be concluded, therefore, that this way of learning could be successful.

Students were questioned whether they would use video tutorials again. The majority (75%) said that they would choose to use video learning again, 25% said they would perhaps choose to use them, and none of the students surveyed said they would not consider using video tutorials again. These results show that more tutorial videos could be made to aid student learning, as they appeared to be useful and would be used again for certain topics.

The students were asked if the availability of more tutorials would be useful for exam preparation with which all students who answered agreed. All the students surveyed said that the video tutorial was helpful to them in some way.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch013

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch013

Video tutorials may be of more benefit to some students than to others, such as those with additional learning needs, where listening to audio is of more assistance than reading notes and books.

Expanding Videos to Other Areas of Chemistry

Videos on various spectroscopic techniques (NMR, IR, MS, UV) are currently part of the online support material for an 8-hour lecture course on organic structural identification, as well as all Organic Chemistry teaching labs in years 1 – 3 where students need to apply these techniques to identify the structure of their reaction products and analyse spectroscopic unknowns.

In addition, a series of videos on the synthesis and characterization of polymers support introductory lectures on Polymer Chemistry in 3rd year, an advanced lecture course in 4th year and at taught MSc level. Within the polymer research group, the videos are even used to train new research students.

In the absence of a practical polymer laboratory, the videos show students how polymers are made and characterized. Topics of this “virtual polymer laboratory” include:

- ○ The radical polymerization of styrene
- ○ The making of nylon-6,10
- ○ Anionic polymerization
- ○ Polymer blends
- ○ Differential scanning calorimetry
- ○ Stress-strain measurements
- ○ Dynamic mechanical thermal analysis

All videos are kept short and cover the selected topic in just 5 – 7 minutes. They serve as an introduction to the topic or a reviewing tool. In addition, the videos allow students who are enroled for the advanced lecture course, but have not done the introductory lecture course, to catch up quickly on any missed material.

Developing videos is a very time-consuming activity and with our many growing teaching, research and administration duties time is scarce. The way we have tried to overcome this problem is by involving final-year undergraduate students in the development and production of new teaching videos. Although at master’s level project students are more likely to benefit from a full research project, many of our final-year BSc project students wish to couple their Chemistry background with their interest in education, teaching and communication. We therefore offer “educational” projects in lieu of a more traditional synthetic or analytical research project. Such projects are particularly attractive to students who wish to become teachers at a secondary school.

Educational projects require students to familiarize themselves thoroughly with and become “experts” in a particular topic (*e.g.* a polymerization method or a polymer characterization technique), before they commence work on developing a teaching video where they try to convey what they learned in a simple, entertaining and original way that would not be easily achieved in a normal lecture. A student will typically produce one video during the 15 weeks of the project. Adequate

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch013

initial training, close supervision, regular updates and advice are essential to ensure that the student remains on track to finish the video in time. Even though the content of script and storyboard needed to be heavily edited by the supervisor, to ensure that the final video was accurate and could be used for teaching purposes, the resulting teaching videos were still quite individual and reflected each project student's own style and ideas.

While supporting videos were well received by our first-year students, students in higher years have more demands on their time and student engagement can be a problem if videos are just considered an optional extra. For this reason, many videos have been integrated into tutorials, webtests, lab assignments, or sometimes even lectures, both as a reminder of this teaching resource and as encouragement to make full use of it.

Conclusions

The current generation of students attending university is different from previous generations as they have grown up with computers, videos games and the internet and so have never experienced a world without information and communication technology. These students have particular technical skills and different ways of learning and thinking, therefore new methods of teaching have to be considered. The use of online teaching videos is a step towards this, and may help students overcome some of the barriers experienced when studying chemistry.

A short video tutorial on the basics of curved-arrow mechanisms was designed for use by first-year students studying chemistry at Heriot-Watt University, as an aid to review the topic before exams (*25*). The main findings suggest that video tutorials can make a positive contribution to student learning, providing an interesting and stimulating alternative/supplement to traditional lectures. Student feedback suggested that the creation of similar videos would be useful for learning.

The main disadvantage of this type of learning tool is the length of time it takes to produce such videos. The drafting of the script and storyboard, the filming of the scenes and the editing of the video all take a considerable amount of time. It is therefore important to consider which topics are worth the effort.

There are many areas of chemistry that could benefit from the creation of similar videos. We have more recently expanded our teaching videos on offer to topics such as NMR, IR, UV spectroscopy and mass spectrometry, as well as a virtual polymer laboratory.

Students like the different approach. Feedback from students was generally positive and justified the work put into the production of the videos. In particular, the videos were appreciated by special needs students and direct-entry students who missed the lecture course.

Experimental

Drawings on a whiteboard (900 mm × 600 mm) were recorded using a camcorder. During filming, the camera was fixed with a tripod stand that was

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch013

positioned above the whiteboard at a distance of about 1.2 meters, with light stands on either side. For consistency, camera and tripod were set up in the same way every time they were used to avoid the pictures moving around excessively on screen and becoming disorientating to viewers. For some of the shots, a digital camera was used to take still photographs. The script was recorded with the help of a dictaphone and then edited with Camtasia Studio (version 6), TechSmith Corp., Okemos, MI. The audio was combined with the recorded video scenes, slides, stills and animations, again using Camtasia Studio.

Acknowledgments

We like to thank all the students who, over the years, contributed to the development of teaching videos as part of their final-year projects: Kimberly S. Gaifer, Cindy S. G. N'Da, Claire Cruickshank, Charmaine Elliot, Caroline S. Harrison, Guillaume Hédir, and Daniel Newton.

References

1. Walls, M.; Kucsera, J.; Walker, J.; Acee, T.; McVaugh, N.; Robinson, D. *Comput. Educ.* **2010**, *54*, 371–378.
2. Tang, T.; Austin, M. J. *Comput. Educ.* **2009**, *53*, 1241–1255.
3. Lohnes, S.; Wilber, D.; Kinzer, C. *Educ. Technol.* **2008**, *48*, 21–27.
4. Bourgonjon, J.; Valcke, M.; Soetaert, R.; Schellens, T. *Comput. Educ.* **2010**, *54*, 1145–1156.
5. Stone, D. *Analyst* **2005**, *130*, 419–420.
6. Lui, D.; Walter, J.; Brooks, D. *J. Chem. Educ.* **2009**, *52*, 599–607.
7. Salomon, G. *J. Educ. Psychol.* **1984**, *76*, 647–658.
8. Marchionini, G. *Educ. Technol.* **2008**, *48*, 39–41.
9. MIT Open Courseware. http://ocw.mit.edu/index.htm.
10. Lazzari, M. *Comput. Educ.* **2009**, *52*, 27–34.
11. Griffin, D.; Mitchell, D.; Thompson, S. *Comput. Educ.* **2009**, *53*, 532–539.
12. Mayer, R. E. *Multi-Media Learning*; Cambridge University Press: Cambridge, U.K., 2001; pp 4–5.
13. Cebeci, Z.; Tekdal, M. *Interdisciplinary Journal of Knowledge and Learning Objects* **2006**, *2*, 7–57.
14. Evans, C. *Comput. Educ.* **2008**, *50*, 491–498.
15. Palmer, S. *Comput. Educ.* **2008**, *50*, 491–498.
16. Wieling, M. B; Hofman, W. H. A. *Comput. Educ.* **2010**, *54*, 992–998.
17. Ardac, D.; Akaygun, S. *J. Res. Sci. Teach.* **2004**, *41*, 317–337.
18. Su, K.-D. *Comput. Educ.* **2008**, *51*, 1365–1374.
19. Alksela, M.; Lundell, J. *Chem. Educ. Res. Pract.* **2008**, *9*, 301–308.
20. The ChemCollective Online Resources for Teaching and Learning. http://www.chemcollective.org/.
21. Fernandez, V.; Sallan, J. M. *Comput. Educ.* **2009**, *53*, 385–392.
22. Ferguson, R.; Bodner, G. M. *Chem. Educ. Res. Pract.* **2008**, *9*, 102–113.
23. Reid, N. *Chem. Educ. Res. Pract.* **2008**, *9*, 51–59.

24. Grossman, R. B. *The Art of Writing Reasonable Organic Reaction Mechanisms*; Springer: New York, 2002; pp 1–40.
25. Video on "Basics of curly arrow mechanisms". http://www.che.hw.ac.uk/teaching/cheak2/Level1/Curlyarrows/Mechanisms.htm.

Downloaded by SUNY ALBANY on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch013

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch014

Chapter 14

Podcasting in Organic Chemistry

Michael D. Mosher*

Department of Chemistry and Biochemistry, University of Northern Colorado, Greeley, CO 80639
***michael.mosher@unco.edu**

Podcasting, a form of asynchronous Internet-based content delivery, has been utilized as supplementary material and full-content in a variety of courses. Examples of its use within Organic Chemistry lectures exist, though limited study of the benefits to this mode of Organic Chemistry instruction has been conducted. An overview of this relatively new technology and the implications of the benefit to Organic Chemistry students are explored in this review.

The distribution of digital audio via the Internet has been known in some form since the mid 1980's, but its use on a wide scale did not occur until just after the turn of the century. In the early 2000's, distribution of media files via the Internet as regularly released programs came into common practice. Fueled by MP3 player software such as iTunes, the technology moved from simple digital audio files that were available on the Internet, to easily distributable and subscribe-able content with a global audience. This new form of digital audio media was termed a "podcast" because it was an Internet-based broadcast of an audio program intended for download to the iPod portable media player, although the programs could be played using essentially any media player, portable or not.

The term podcast was initially intended to refer to only digital audio media. Yet, as the speed of the Internet and technological capability of the end-user improved, the type of media that could be delivered and used became more varied. Expansion of this subscription-based media delivery included the enhanced podcast (audio media coupled with single frame pictures as 'chapter' markers) and vodcast (video-enhanced audio broadcast media). Currently, the term 'podcast'

In Advances in Teaching Organic Chemistry; Duffy-Matzner, J., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2012.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch014

is often used to encompass all of these enhanced forms of audio media delivery in addition to the original audio media.

Podcasting elicits significant appeal as a way to disseminate information on a regular schedule to a mass audience. Even as a fairly new process, the technological capability is such that many companies, agencies, educational institutions in addition to the general public have found an inexpensive venue from which to launch a weekly podcast. While some use it as a novelty to attract interest or encourage further study, there is a growing demand for the use of podcasting as the mode of dissemination of all material for a course. For example, podcasts have ranged from the early "radioshow" style to distance education with multimedia. In 2012, very few companies and schools seem immune from podcasting. They are easily accessible and able to be used by anyone with access to a computer.

Audio Podcasting

Audio podcasts originally began as subscription-style radio shows. The media was thought of, in those early years, as an alternative to radio or television. And given the technology of the 1990's and early 2000's, audio podcasts easily fit the requirements of that alternative. The audio podcast is relatively easy and inexpensive to create. Essentially, the basic podcast can be made with any digital recording device or microphone plugged into a computer. The digital audio is then recorded and saved in a file format that can be distributed to listeners. At this point, access to a server on which to store the files is all that is needed. Those servers distribute the audio files as they are uploaded to all of the subscribers to the podcast.

Audio podcasts require very little in terms of technology to create and very little software knowledge to produce. Thus, creating audio podcasts can be an easy way to join the podcasting community. Unfortunately, due to the nature and limitations of audio only media, the audio podcast is difficult to implement in Organic Chemistry education. Organic chemistry, a subject that requires a high visual demand, can be quite difficult to teach without drawings, images, and other visual aids. Because of this, the use of audio podcasts in Organic Chemistry has been limited to summaries of the lecture or related information that does not have a visual component. Some examples of this format do exist. For instance (*1*), Sean Hickey (University of New Orleans), Marietta Schwartz (University of Massachusetts Boston), Jean-Claude Bradley (Drexel University) (*2*), and K. Peter Volhardt (UC Berkeley) have produced a number of podcasts that include study guides and recorded lectures in audio format. Bradley's podcasts from 2005 are one of the earliest still available on iTunesU. He has since expanded, as many others have, to the use of vodcasting. Ed Smith (Imperial College London) has produced a series of audio podcasts with a more refined flair in that they are recorded shows outside of the normal lecture hall. Unfortunately, the lack of video or pictures in this type of podcasts makes them difficult to follow except as a review of a lecture that you have already attended.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch014

Video and Images in Podcasting

While audio podcasting is still in use today within the Organic Chemistry lecture setting, the addition of video or images to supplement the information in a podcast greatly enhances the utility of the resource. Initially, the use of images as chapter markers was implemented. These so-called enhanced podcasts did not allow the narrator to highlight a particular structure or add any movement other than changing the image that was displayed. Moreover, in the initial stages of the Internet, the enhanced podcast file size grew dramatically as more and more images were added. The size of the final product was often much greater than could be handled by the typical Internet capability of the student at home.

By 2008, the use of video in podcasting became the norm. Students began to have access to cable-based and wireless Internet services that could handle the large file sizes of a vodcast, and the added functionality made these videos quite useful as teaching and learning tools. Unfortunately, vodcasting of any sort is more technologically demanding than the standard audio podcast. Depending upon how the podcast is designed, this could require the use of digital video cameras, movie editing software, computer screen or blackboard capture software, and/or computer tablets to capture pen movements (*3*). The utility of the video enhanced podcast seems to be the driving force for the sheer number of instructors that choose this method for educating students.

Vodcasting has been utilized in many different ways in Organic Chemistry instruction. For example, Thomas Poon (Claremont Colleges) developed a series of video enhanced podcasts as warmups for the actual lecture. These short Pre-Lectures were developed early on in podcasting (2004-2005), but their utility remains as tutorials on specific topics in Organic Chemistry (*4*). In another example, James Norwick (University of California Irvine) produces a set of video-captured lectures. In similar fashion, J. Michael McBride (Yale) has created a videotaped lecture series for podcasting that even includes guest speakers as part of the lecture. Both of these examples require that a helper operate a video camera during the normal lecture periods, and that the video camera is capable of capturing everything displayed on overheads, powerpoint shows, and the blackboard (*5*). The benefit to conducting the vodcast in this manner is that the additional time needed to create the digital media for distribution is limited only to video editing and packaging. In a further example, Andy Aspaas (Coon Rapids Campus of Anoka-Ramsey Community College) has produced a vodcast using a computer screen capture and voice over to relay the information (*5*). It is clear to see that a wide variety of methods are being utilized to create the Organic Chemistry vodcast (from the short tutorial to the hour-long lecture).

While a couple of presentations have been given on the use of podcasting in Organic Chemistry (*6*, *7*), there is a dearth of publications on the practice and outcomes of this method of information delivery in the lecture setting. This is not the case in other disciplines. For example, Brunet and Cuggia (*8*) have described the method for podcasting in the medical school setting, and reviews of the use of the technology in health education (*9*, *10*) have been published. Dentistry (*11*) and nursing (*12–14*) programs have illustrated the use of podcasting as a useful tool. While a recent study in a nursing program has indicated that any benefit to podcasting is very learner-centered (*15*), there generally exists strong support for the use of podcasting across the health sciences, particularly if the media is coupled with face-to-face lectures (*16–18*). In fact, a large majority of the utilization of podcasting and particularly vodcasting has been developed for use within the health-related fields, either for formal education or informational education (*19–21*). The extremely high demand for distance medicine and video- and tele-conferencing for health care and related topics has lead to the exploration of the use of Internet-based media in that field (*22*).

The limitations of video-based podcasting are apparent once one has made the decision to include this type of media as part of their Organic Chemistry course materials. A learning curve to the efficient use of software for digital video editing exists, and this can be compounded based upon what specific format for the media that the instructor wishes to implement. Video capture of an existing lecture is the simplest of the vodcasting formats, but this too has limitations of another kind. The video camera must be able to record images that are displayed to the class, while at the same time displaying the instructor as the topics are explained. Often, this leads to either washed-out projected images (a technical problem) or very small images due to zooming out to include the instructor and the projected image in the camera window. These problems can be overcome with either a combination of multiple cameras and digital video editing software, or by upgrading to screen capture software (for projected images) that limits the instructor to existing as a voice-over.

Should the format of the intended vodcast utilize a rehearsed screen capture and voice-over of a lecture or specific topic in Organic Chemistry, the technical limitations are also prevalent. Software to handle most any screen capture is available. The cost of that software can be tailored to any budget. However, moving to a more natural form of writing using a writing tablet requires the expense of additional hardware for the computer. Good quality writing tablets can, in some cases, greatly impact a limited budget.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch014

Implementation

The learning curve for implementation of the vodcast into Organic Chemistry can result in a more important problem, time to complete the task. While most faculty members have limited time for instruction, trying to improve their instruction by providing podcasts (with or without video) can seriously eat into any available time. The podcasts are still created in many cases, because of the perceived or recognized value of the podcast to the education of the student.

As noted above, very few discussions of the benefit of podcasting in Organic Chemistry have been published in the literature. One such discussion (*23*) involved the use of vodcasts as a method for enhancing student preparation in the laboratory. That study showed illustrated the utility of this media in terms of enhancing the laboratory experience. While the outcomes of the use of podcasting in Organic lectures have not been disseminated, the advantages of this mode of instructional delivery have been fully described in other disciplines. For example, attitudinal and informational surveys in a podcast-enhanced biochemistry course indicated

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch014

that students look upon the media favorably, whether a measureable benefit exists or not (*24*, *25*). The use of video-enhanced podcasts was noted as a benefit over the audio-only podcasts (*26*). In a detailed study conducted within a pharmacology course, researchers were able to determine that in addition to student enjoyment of podcasting, those students that utilized the podcasts showed an improvement on examination performance (*27*). This improvement may also exist for those students that use English as their second language (*28*). Nonetheless, in nearly every example of the use of podcasting in formalized education courses, class attendance (*29*) has not been found to be affected by recording and distributing podcasts.

The benefits of podcasting in the educational setting have also been explored outside of the traditional lecture course. Students become more engaged, according to a study conducted within a nursing program (*30*), in their distance education courses with the use of podcasts. General delivery of information that is particularly visual in nature can be done by podcasts, as is demonstrated by the development of pediatric otologic procedure videos (*31*). While video-enhanced podcasts are indicated in visual demonstrations, audio podcasting has also been utilized within the health field as an educational tool (*32–34*). The success of all forms of podcasting is compelling, and suggests that these forms of media may be of use to the Organic Chemistry lecture community.

Conclusion

The future of podcasting, vodcasting, and related internet-based media for use in Organic Chemistry lectures still resides in the benefits of this relatively new technology. While students perceive face-to-face interaction as having the greatest benefit to their overall education, the ability to review, study, and explore alternate topics outside of the classroom is greatly enhanced through podcasting media. As the technology improves, new methods and media may be created. An interactive asynchronous subscription-based lecture may be just around the corner.

In the current state of technology, the benefits of implementing a podcast or vodcast in Organic Chemistry lectures exist. Whether that benefit is limited to student appreciation of the additional out-of-class support or unbounded by the podcasts potential to improve understanding in every student, it is clear that digital media has a place in our courses. Further evaluation and assessment of these forms of instructional delivery are needed to more clearly identify the impact.

References

1. The method to find these, and other, podcasts is outlined at this URL. http://www.apple.com/itunes/podcasts/ (accessed March 19, 2012).
2. Bradley, J.-C.; Lang, A. *Abstracts of Papers, 238th National Meeting of the American Chemical Society*; Washington, DC, Aug 16−20, 2009; American Chemical Society: Washington, DC, 2009; CHED 400.
3. Nichols, M. A. *Abstracts of Papers, 40th Central Regional Meeting of the American Chemical Society*, Columbus, OH, June 10−14, 2008; CRM 289.

4. Organic Chemistry Help eMediately (OCHeM.com). Organic Chemistry Tutorials. http://ochem.jsd.claremont.edu/tutorials.htm (accessed March 19th, 2012).
5. Available through iTunesU. Information on accessing this archive. http://www.apple.com/education/itunes-u/ (accessed March 20, 2012).
6. Picione, J.; Murphy, K. *Abstracts of Papers*, *233rd National Meeting of the American Chemical Society*, Chicago, IL, March 25−29, 2007; American Chemical Society: Washington, DC, 2007; CHED 023.
7. Bagga, K. K. *Abstracts of Papers, 240th National Meeting of the American Chemical Society*, Boston, MA, Aug 22−26, 2010; American Chemical Society: Washington, DC, 2010; CHED 6.
8. Brunet, P.; Cuggia, M.; Le, B. P. *Stud. Health Technol. Inform.* **2011**, *169*, 248–252.
9. Jham, B. C.; Duraes, G. V.; Strassler, H. E.; Sensi, L. G. *J. Dent. Educ.* **2008**, *72*, 278–281.
10. Alikhan, A.; Kaur, R. R.; Feldman, S. R. *J. Dermatol. Treat.* **2010**, *21*, 73–79.
11. Reynolds, P. A.; Mason, R.; Eaton, K. A. *Br. Dent. J.* **2008**, *204*, 145–149.
12. Smith-Stoner, M.; Willer, A. *Nurse Educ.* **2003**, *28*, 66–70.
13. DiMaria-Ghalili, R. A.; Ostrow, L.; Rodney, K. *J. Nurs. Educ.* **2005**, *44*, 11–18.
14. Forbes, M. O.; Hickey, M. T. *Nurse Educ.* **2008**, *33*, 224–227.
15. Gipson, M.; Richards, J. *Nurse Educ.* **2011**, *36*, 161–164.
16. Long, S. R.; Edwards, P. B. *J. Nurses Staff Dev.* **2010**, *26*, 96–103.
17. McCartney, P. R. *MCN Am. J. Matern. Child. Nurs.* **2006**, *31*, 270.
18. McKinney, A. A.; Page, K. *Nurse Educ. Pract.* **2009**, *9*, 372–376.
19. Ragon, B.; Looney, R. P. *Med. Ref. Serv. Q.* **2007**, *26*, 17–26.
20. For an informational example, see: Turner-McGrievy, G.; Tate, D. *J. Med. Internet Res.* **2011**, *13*, e120.
21. Schroeder, H. *Med. Ref. Serv. Q.* **2010**, *29*, 109–120.
22. Mars, M. *Telemed. J. E. Health* **2012**, *18*, 32–37.
23. Hallaq, T.G.; Holman, R.W.; Lohse, S. *Chem. Educ.* **2011**, *16*, 152–154.
24. Lyles, H.; Robertson, B.; Mangino, M.; Cox, J. R. *Biochem. Mol. Biol. Educ.* **2007**, *35*, 456–461.
25. Vogt, M.; Schaffner, B.; Ribar, A.; Chavez, R. *Nurse Educ. Pract.* **2010**, *10*, 38–42.
26. Shantikumar, S. *Med. Teach.* **2009**, *31*, 535–538.
27. Meade, O.; Bowskill, D.; Lymn, J. S. *BMC Med. Educ.* **2009**, *9*, 74.
28. Greenfield, S. *J. Nurs. Educ.* **2011**, *50*, 112–114.
29. Schlairet, M. C. *J. Nurs. Educ.* **2010**, *49*, 529–533.
30. Stiffler, D.; Stoten, S.; Cullen, D. *Comput. Inform. Nurs.* **2011**, *29*, 144–148.
31. Abreu, D. V.; Tamura, T. K.; Sipp, J. A.; Keamy, D. G., Jr.; Eavey, R. D. *Ear Nose Throat J.* **2008**, *87*, 208, 210–211.
32. Savel, R. H.; Goldstein, E. B.; Perencevich, E. N.; Angood, P. B. *J. Am. Med. Inform. Assoc.* **2007**, *14*, 94–99.
33. White, J. S.; Sharma, N.; Boora, P. *Med. Teach.* **2011**, *33*, 941–943.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch014

34. Bensalem-Owen, M.; Chau, D. F.; Sardam, S. C.; Fahy, B. G. *Neurology* **2011**, *77*, e42–44.

Downloaded by NORTH CAROLINA STATE UNIV on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ch014

Subject Index

A

Alkene reactants, 93*t*
Aqueous sonogashira synthesis, 19*s*
Aromatic compounds, 34*c*
Audio podcasting, 226
Azlactone derivatives, 20*s*

B

2-(Benzhydrylsulfinyl)acetamide enantiomers, 21*f*
Blended organic chemistry, curriculum reform
  CHEM 115L experiment list, 167*t*
  CHEM 229L experiment list, 167*t*
  CHEM 237L experiment list, 169*t*
  design, 157
  faculty research summer preparation timeline, 170*t*
  implementation, 157
  laboratory sequence, 161
  lecture sequence, 158, 160*t*
  overview, 151
  South Dakota State University, 155
Bloom's Taxonomy, 97

C

Carbonyl chemistry
  class average trend, 117*f*
  exams, 117
  exams *vs.* topics, 116*t*
  overview, 115
  problem source, 117
    mechanisms, 120, 120*t*
    reaction numbers, 118, 119*t*
    textbooks, 118, 118*t*
    timing, 119
  topic order effect, 120*t*
Chemical heritage organizations, 148
Chemical history books, 147
CHEM 115L experiment list, 167*t*
CHEM 229L experiment list, 167*t*
CHEM 237L experiment list, 169*t*
Clark Still, 146
Clayton Heathcock's synthesis, 141
Cognitive structure linking, 94
Commercially available fluorophores, 29*c*
Compound **25** synthesis, 33
Conjugated polymers, 39*c*
Conjugated polymer synthesis, 44
Coumarin synthesis, 22*s*
Current curriculum *vs.* predominantly wet lab curriculum, 67*f*
Curved-arrow mechanisms, 214, 218*f*
Cyclodextrins, energy transfer, 43

D

Daily lesson sheet, 192*f*
Desoxy compound, 144*s*, 145*s*
Discovery-based labs
  guided-inquiry labs, 3
    effectiveness, 7
    laboratory courses, 7
    purification, 7
    reaction analysis, 4, 5*f*, 6*f*
    research-like laboratory courses, 7
    unknown identification, 3, 4*f*
  overview, 1
Dry lab, student ratings, 68*f*

E

E. J. Corey's synthesis, 139
E2 elimination mechanisms, 217*f*
Exam cover sheet, 193*f*

F

Faculty research summer preparation timeline, 170*t*
Final course grade predictability, 123, 125*f*, 126*f*, 128*f*
Flashcards, 199, 200*f*
Fluorescence amplification, 40*f*
Fluorescence emission, 43*f*
Fluorescent polymer **47** synthesis, 44
Friedel-Crafts alkylation, 219*f*

Downloaded by 89.163.34.136 on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ix002

Downloaded by 89.163.34.136 on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ix002

G

Georgia Gwinnett College, 189
  blackboard course management web page, 195*f*
  integrated educational experience goals, 191*f*
  public web page, 195*f*
  Thayer method, 189, 204
Grade distribution, 102*f*, 102*t*, 103*t*, 104*f*, 105*t*, 106*f*, 106*t*
Grading rubrics, 62*t*
Guided-inquiry labs, 3
  effectiveness, 7
  laboratory courses, 7
  purification, 7
  reaction analysis, 4, 5*f*, 6*f*
  research-like laboratory courses, 7
  unknown identification, 3, 4*f*

H

Historical example integration
  chemical heritage organizations, 148
  chemical history books, 147
  Clark Still, 146
  Clayton Heathcock's synthesis, 141
  desoxy compound, 144*s*, 145*s*
  E. J. Corey's synthesis, 139
  Marshall Gates, 143
  methyl homosecodaphniphyllate, 141, 141*f*, 142*s*
  morphine synthesis, 143, 143*f*
  Napoleon's Buttons, 134, 135*t*, 136*t*, 137*t*
  overview, 131
  Periplanone B, 146*f*
  prostaglandins, 139*f*, 140*s*
  researcher profiles, 142
  textbooks, 133

I

Image podcasting, 227

L

Lab program design, 56
  course structure, 56
  dry labs, 57
  electronic material distribution, 57
  program content, 58
Lab program revision, goals, 55
Lab schedule, 56*f*, 57*t*
Lab technique videos, 200, 201*f*, 203*f*
Likert-style survey, 65*f*

M

Marshall Gates, 143
Methyl homosecodaphniphyllate, 141, 141*f*, 142*s*
Mobile apps, 197
Morphine synthesis, 143, 143*f*

N

Nanoparticle fabrication, 40, 41*f*, 42*c*
Napoleon's Buttons, 134, 135*t*, 136*t*, 137*t*
Near-infrared emitting fluorophores, 29*c*
Neural scaffolding
  alkene reactants, 93*t*
  challenges, 88
  data gathering, 101
  grade distribution, 102*f*, 102*t*, 103*t*, 104*f*, 105*t*, 106*f*, 106*t*
  implementation, 90
  instructional methods, 91
    Bloom's Taxonomy, 97
    chunking, 93
    cognitive structure linking, 94
    fading, 98
    framing, 92
    reinforcement, 94, 95*f*
    reverse engineering, 96, 97*f*
    Socratic method, 95, 95*f*
  overview, 85
  pedagogical training, 91
  p-ethylbenzaldehyde, 96*f*
  qualitative data, 106
  quantitative data, 101
  statistical methods, 101
  supplemental instruction, 89

O

Online video learning, 211
Organic chemistry curriculum, student encouragement
  learning assessment results, 81, 82*t*
  overview, 73
  problems, 74

Downloaded by 89.163.34.136 on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ix002

- timely mnemonic, 78
- WHIP approach, 75

Organic experiment themes, 16
- discovery-based work, 21
- green chemistry, 17, 19*f*
- real-world relevant compounds, 16, 17*f*
- student design encouragement, 20

Organic fluorophores
- aromatic compounds, 34*c*
- commercially available fluorophores, 29*c*
- compound **25** synthesis, 33
- conjugated polymers, 39*c*
- conjugated polymer synthesis, 44
- cyclodextrins, energy transfer, 43
- fluorescence amplification, 40*f*
- fluorescence emission, 43*f*
- fluorescent polymer **47** synthesis, 44
- nanoparticle fabrication, 40, 41*f*, 42*c*
- near-infrared emitting fluorophores, 29*c*
- overview, 27
- polymer-squaraine hybrid thin films, energy transfer, 40*f*
- polymer **45** synthesis, 44
- polyphenyleneethynylene, energy transfer, 32*f*
- solvatochromic dyes, 38*c*
- spin coater, 39*f*
- squaraine compound synthesis, 35*s*
- squaraine 12d
  - color, 36*f*
  - normalized visible spectra, 36*f*
  - synthesis, 33*s*
- squaraine dye synthesis, 28, 32
- symmetrical squaraines, 31*c*
- synthesis, 37
- terrylene diimide synthesis, 30*s*
- thin film formation, 38

Organic laboratory renewal
- aqueous sonogashira synthesis, 19*s*
- azlactone derivatives, 20*s*
- 2-(benzhydrylsulfinyl)acetamide enantiomers, 21*f*
- coumarin synthesis, 22*s*
- curriculum renewal, 15
- organic experiment themes, 16
  - discovery-based work, 21
  - green chemistry, 17, 19*f*
  - real-world relevant compounds, 16, 17*f*
  - student design encouragement, 20
- pyrrole-2-carboxylic acid decarboxylation, 23*s*
- semicarbazone formation, 22*s*
- teaching-stream faculty model, 14
- tertiary amine anti-fungal analog, 21*s*
- TPAP-catalyzed oxidation, 18*s*
- undergraduate research, University of Toronto, 13

P

Periplanone B, 146*f*

P-ethylbenzaldehyde, 96*f*

Podcasting
- audio, 226
- image, 227
- implementation, 228
- overview, 225
- video, 227

Podcasts, 198*f*, 202*f*

Polymer-squaraine hybrid thin films, energy transfer, 40*f*

Polymer **45** synthesis, 44

Polyphenyleneethynylene, energy transfer, 32*f*

Prostaglandins, 139*f*, 140*s*

Pyrrole-2-carboxylic acid decarboxylation, 23*s*

S

Sapling learning's material distribution, 58*f*

Scientific exposure appropriateness, 66*f*

Scientific writing
- assignments, feedback, 64*t*
- current curriculum *vs.* predominantly wet lab curriculum, 67*f*
- dry lab, student ratings, 68*f*
- evaluation, 63
  - student survey results, 63
- grading rubrics, 62*t*
- lab program design, 56
  - course structure, 56
  - dry labs, 57
  - electronic material distribution, 57
  - program content, 58
- lab program revision, goals, 55
- lab schedule, 56*f*, 57*t*
- Likert-style survey, 65*f*
- overview, 51
- program revision parameters, 53
- Sapling, feedback, 64*t*
- Sapling learning's material distribution, 58*f*
- scientific exposure appropriateness, 66*f*
- student demographics, 54*t*

Second semester organic course renovation, 177

Downloaded by 89.163.34.136 on November 5, 2012 | http://pubs.acs.org
Publication Date (Web): November 5, 2012 | doi: 10.1021/bk-2012-1108.ix002

Semicarbazone formation, 22*s*
Solvatochromic dyes, 38*c*
South Dakota State University, 155
Spin coater, 39*f*
Squaraine compound synthesis, 35*s*
Squaraine **12d**
  color, 36*f*
  normalized visible spectra, 36*f*
  synthesis, 33*s*
Squaraine dye synthesis, 28, 32
Symmetrical squaraines, 31*c*

T

Teaching-stream faculty model, 14
Terrylene diimide synthesis, 30*s*
Tertiary amine anti-fungal analog, 21*s*
TPAP-catalyzed oxidation, 18*s*
TsoiChem App, 192, 199*f*

U

Undergraduate organic chemistry, 21st century student success
  course outcome goals, 191*f*
  daily lesson sheet, 192*f*
  education challenge, 187
  exam cover sheet, 193*f*
  exam problem, 193*f*
  flashcards, 199, 200*f*
  Georgia Gwinnett College, 189
    Blackboard course management web page, 195*f*
    integrated educational experience goals, 191*f*
    public web page, 195*f*
    Thayer method, 189, 204
  lab technique videos, 200, 201*f*, 203*f*
  overview, 185
  podcasts, 198*f*, 202*f*
  STEM disciplines, 186
  TsoiChem App, 199*f*
Undergraduate research, University of Toranto, 13

V

Video podcasting, 227
Video preparation, 216
Videos
  advantages, 211
  aims, 213
  content, 214
  curved-arrow mechanisms, 214, 218*f*
  disadvantages, 212
  E2 elimination mechanisms, 217*f*
  Friedel-Crafts alkylation, 219*f*
  overview, 209
  preparation, 216

W

WHIP approach, 75